

TECHNICAL NOTE R-192

A MISSION FOR SURVEYING AND
MAPPING THE LUNAR SURFACE

April 1966

Prepared For

SPECIAL PROJECTS OFFICE
RESEARCH PROJECTS LABORATORY
GEORGE C. MARSHALL SPACE FLIGHT CENTER

By

RESEARCH LABORATORIES
BROWN ENGINEERING COMPANY, INC.

Contract No. NAS8-20166

Prepared By

S. N. Heaps

ABSTRACT

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A three-man lunar mission has been planned in which eleven remote sensing instruments are operated for eight days in a polar orbit. From the elevation of 81.5 km (44 n mi), the high resolution stereoscopic photographs and celestial navigation sightings provide accurate location data for the Earth-science observations. The mission is one of a series proposed under the Apollo Applications Program.

Approved:



J. E. White, Jr.
Research Projects
Coordinator

Approved:



R. C. Watson, Jr.
Vice President
Advanced Systems and Technologies

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INTRODUCTION

Preliminary mission assignments have been made for the Apollo Applications flights.¹ An orderly series of objectives consistent with flight capabilities has guided the planning of these flights and their schedule. A number of space missions will precede Flight 511, and the opportunity for incorporating their results into the Flight 511 program will occur at a later date. The present experiment complex does not depend upon this. It is presumed that Flight 511 is the first three-man flight to circle the Moon with a series of polar orbits. The experiments selected for this flight will provide data of value in the study of lunar geophysics, geology, geography, and geodetics. Since most of the lunar surface may never be visited, a specific objective is to obtain orbiter observations which will serve to divide and delineate the lunar surface into a few typical areas suitable for immediate exploration. It also is desirable to locate specific anomalies which may serve as mission objectives in terms of natural resources or sites of scientific significance. It is desirable additionally to locate suitable landing sites for the lunar surface visitations. To attain these objectives, it is planned to evaluate as many surface characteristics as possible and to record the location of each measurement site.

The sensors on this flight detect the characteristics of the Moon by its emission of light, infrared, radio, microwave, radar, ultraviolet, x-ray, gamma ray, and alpha particle radiation, and also provide a meteor count above the Moon's surface. The selection of the experiments has been guided by the recommendations of the several working groups of the Manned Space Science Coordinating Committee. The bioscience experiments, however, are beyond the scope of the mission. Experiments in astronomy, space physics, and engineering have also received a low priority, and no Earth surface or atmospheric experiments are planned.

As the flight characteristics, capabilities and limitations were reviewed, a few basic facts appeared as guide lines for the continuation of plans. For example, the successive equatorial crossings were found to be so close together that the use of a pair of high resolution cameras will permit contiguous aerial photographs. Hence the need for wide angle or panoramic cameras in addition to those of high resolution is unnecessary. Also, since everything is photographed with high resolution, the astronaut task of selecting specific subjects for the special photographs is bypassed. Since the capability for high resolution mapping exists, a high priority is assigned to this task with the knowledge that no other flight will have this opportunity. Celestial navigation equipment is added to the flight payload to add additional value to the photographs. A photographic mapping schedule is planned and in order to preserve the pattern no experiments are planned which require deviations of the spacecraft's normal orbit.

An additional fact is the speed with which the lunar surface passes beneath the spacecraft. Continuous operation of all sensors and cameras is planned for the full eight-day orbital period. Hundreds of miles of lunar information will be missed if a few minutes of time are taken to change film, check instrument calibration, or to lubricate bearings. These things must be considered in the original instrument design or must be included in the normal operation cycle where they are best managed by machines instead of by men. The repetition rate and the monotony of the operational cycle are beyond human capability and endurance.

An additional fact to be recognized is the value of the simultaneous measurements. The sensors on board the orbiter are all sensing the same surface sample from the same flight with the same lunar libration and Sun angles. When the orbiter has passed, it will never return.

MISSION OUTLINE

MISSION DESCRIPTION

Since a large number of experiments are in simultaneous operation on board a rapidly moving laboratory, there will be a rapid accumulation of large quantities of data. The equipment must be highly automated for this reason. The tasks of the astronauts will accordingly be largely unassigned. Remote monitoring and control capability will be emphasized in each experiment to permit data editing, and judgement during unforeseen or unpredictable situations. Data editing will be accomplished as it is recorded because all data is considered valuable, and lost data can never be recovered. The short time at each geological site prevents manned operations such as pointing, readjusting, data evaluation and computation, and any actions based upon decision. Prior to the sunlight phase of the first orbit, all instruments are expected to attain normal operation with only a few moments of astronaut attention. Much of the astronaut time and capability will be used for communication and flight control, and for starting and stopping the operation of the sensing apparatus. Periodic or routine checking of all the individual monitor and control panels should insure success of all aspects of the lunar surface measurements program.

VEHICLE CONFIGURATION

This flight incorporates the Saturn V, the Command Service Module, and the Lunar Excursion Module with descent and ascent stages¹. For the orbital lunar missions, the Saturn V payload is 91,500 pounds². This is divided to provide for 8000 pounds of experimental apparatus and 83,500 pounds of spacecraft with basic Apollo capability.

Within the basic Apollo capability are the following provisions:

Volume:	Pressurized storage space within the LEM Lab	247 ft ³
	Unpressurized storage space within the LEM Lab	1500 ft ³
	Unpressurized storage space within the SM sector I	210 ft ³
Attitude Control:	0.5° accuracy for 24 days. Drift rate is less than 0.05° per second	
Electrical Power:	30 V dc and 115 V ac (3 phase, 400 cycles). The total energy available is 450 kWh, with consumption rates up to 5700 W.	
Radio Communication:	Voice, telemetry, and television between spacecraft and Earth is provided using Apollo format, Apollo data rates, and Apollo frequencies. The data rate capability is 51,200 bits/sec; however, time-sharing with flight monitoring telemetry is necessary. Simultaneous transmission of digital and analog data is provided and analog transmission may be simultaneous on three subcarriers. Additional capability provides for voice communication between the astronauts.	
Data Storage:	Total photographic film and magnetic tape to be returned to earth is 250 lb. Data may be sent by appropriate channel to storage by analog recording, or by analog to digital conversion to a recorder, or to the communication system for direct transmission to Earth. The basic Apollo data storage is a 14-channel magnetic tape recorder (5 digital and 9 analog). The tapes are 1 inch wide and 2400 feet long.	
Life Support:	Three men for 45 days. Cabin environment is held near the following values:	
	Temperature	75°F
	Pressure	5 psi
	Humidity	40-70%

ORBITAL CHARACTERISTICS

This mission is a three-man flight of fourteen days' duration including an eight-day period in orbital circuits around the Moon. The lunar orbit of circumpolar inclination is to be established at an elevation of 44 n mi (81.5 km). The period for this height is 116 min (6960 sec); hence, the allotted time will permit 99 revolutions. Because of the Moon's rotation of 1.12 deg during each revolution of the orbiter, the successive equatorial crossings will be displaced westward 20 statute miles (32.2 km). The 99 revolutions will traverse a lunar surface distance of 671,000 miles (1.08 million km) at an effective speed of 0.975 mi/sec (1.570 km/sec). The angular velocity of the orbiter as it passes directly over a lunar surface point will appear to be 1.10 declination deg/sec (0.0192 rad/sec). It is most desired that the position of the orbit throughout the eight days will be favorable for photographic mapping of a large portion of the near-side of the Moon as indicated in Figure 1, and no photographs would be made of the farside. The other sensing devices which do not depend upon the Sun's position will operate continuously. In practice the lunar orbit shown in Figure 1 may be prohibitive in terms of flight dynamics and fuel efficiency. From the orbiter height of 81.5 km, the lunar horizon will be 521 km from the suborbiter point on the lunar surface, and the lunar disc diameter will subtend 145.6 deg. These characteristics have been summarized in Table 1.

LUNAR SURFACE STUDIES

Geodesy

From the vantage point high above the lunar terrain the gravitational field and the figure of the Moon may be determined more easily than by surface measurements. During the eight days of polar orbit nearly two-thirds of the surface will pass beneath the orbiting spacecraft and a close grid of measurements will permit an accurate determination of contour lines for surface elevation and for the gravitational field. Magnetic

ORBIT ALTITUDE - 44 n. mi.

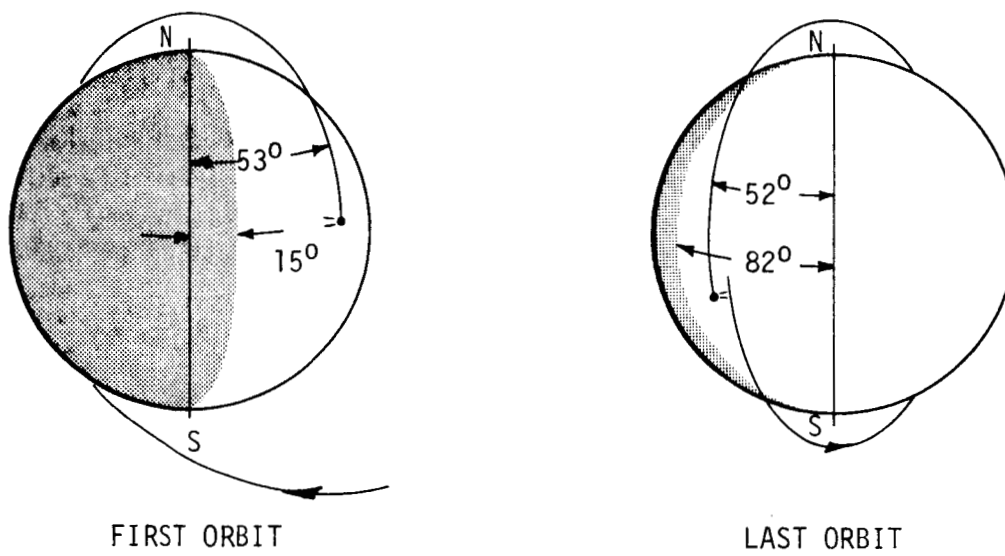


Figure 1. Circumpolar Orbits for Lunar Surveying and Mapping Mission

TABLE 1
SUMMARY OF FLIGHT 511 DYNAMICS

Orbit:	A lunar orbit with circumpolar inclination (see Figure 1)
Elevation:	44 n mi) (81.5 km)
Duration:	8 days in orbit; total mission, 14 days
Period:	116 min (6960 sec)
Number:	99 lunar revolutions
Horizon Distance:	521 km (324 mi) from suborbiter surface point.
Tracking Error:	1.06 degrees selenographic longitude per revolution (32.2 km/rev. at lunar equator)
Lunar Traverse Length:	(99 \times circumference) 1.08×10^6 km (671,000 mi)
Traverse Speed:	1.57 km/sec, 0.0517 lat deg/sec
Angular Velocity at Lunar Surface Zenith:	0.0192 rad/sec (1.10 deg/sec)
Configuration:	Saturn V, Command Service Module, and Lunar Excursion Module A/S and D/S. (LEM Lab)

measurements are possible; however, this field is expected to be weak and more closely related to solar-wind and Sun-spot activity. The permanent magnetic fields are expected to be associated with local anomalies which are best studied by surface measurement. The measurement of the Moon's shape and gravitational field are related. Both depend upon good data from three independent measurement systems. First is the star tracker experiment which is designed to provide celestial observations on a number of the stars normally used in navigation. These angular measurements are used in conjunction with accurate time measurements derived from a precision clock or from the Earth by radio link. The radio time measurements may not be best for continuous operation because of the delay in signal transit time between the Earth and the Moon. Doppler effects will further complicate the radio time signals because of the high speed of the spacecraft. An additional problem results from loss of radio contact during the spacecraft passage behind the Moon. A precision oscillator is recommended for timing purposes with radio time checks periodically at favorable spacecraft positions.

The usual navigational chronometer is not suggested because an electrical output is needed to permit digital computer processing of the data. The third measurement system is the radio altimeter. This establishes the shape of the Moon with the spacecraft orbit (trajectory) as a reference base. This shape is recomputed for a new section of the Moon on each orbital circuit of the spacecraft to obtain an accurate description of the lunar figure.

Gravity instrument readings have been considered as lunar orbiter objectives. The feasibility of direct measurements is questionable, and the gravitational field is expected to be delineated alternatively through study and computation of the perturbations in the spacecraft's orbit. It is expected that the perturbations will correlate with the newly determined figure of the Moon and with tidal forces due to the Sun and the Earth. The perturbation factors may be compensated by computational procedure to arrive at the form of the field for a nonrotating spherical Moon.

The shape of this field is related to the mass distribution within the Moon. A rock density distribution pattern within the Moon is expected. Any major deviation from the expected gravitational pattern must be explained in terms of anomalies in the mass distribution within the Moon. This in turn relates to the processes by which the Moon was formed.

Heat balance is believed to be a geodetic problem for both Earth and Moon. Some measurements and interpretation have been made for the Earth, but good measurements are not easily obtained. The heat flow studies depend upon surface temperature mapping. Local temperature variations prevent the measurement of world-wide effects. This may be only partially true for the Moon. The solar influence on surface temperature is the dominant factor; however, the microwave and infrared data have provided consistent patterns of isothermal contours and a number of "hot spots" may be discerned during a lunar eclipse. Further study of the patterns and knowledge of the surface thermal characteristics should reveal heat sources within the Moon and the associated heat-flow patterns.

Topography

The morphological characteristics of the Moon are to be determined at several scales of magnitude through the coordination of several sensing systems carried in the orbiter. First an accurate location of all surface features is to be determined by correlation of photographs with selenographic coordinates as determined by star tracker data. The aerial mapping cameras for this will be provided with a mechanical image follower. This permits two successive pictures to be made of the same surface spaced 4.5 seconds apart in time. This provides a 5-degree parallax to enhance the stereoscopic imagery of the pair. An effort is made to maintain a 1-meter resolution in photographic quality; therefore, a complete study of all the photographs will take many years.

Two radar measurement systems provide further indications of the surface features. The radio altimeter does not have a narrow beam and its maximum capability for resolution is an area many times larger than the details found in the photographs. The distance to the suborbiter position on the surface may be sampled almost continuously and general elevation details will be revealed and measured. The inability of this instrument to scan the area below prevents contiguous elevation coverage of the surface between adjacent orbits; however, the data should provide complimentary and supplementary data for the stereo camera survey. By contrast, the radar imagery system which is scheduled for simultaneous operation with the radio altimeter system does have an inherent capability for more detailed elevation sensing. This is not being exploited since the data-processing requirements impose an excessive burden on both tape or film or on the telemetering capacity.

An additional topographic study which is considered to be feasible is the result of the analysis of the radar echo waveform. This wave normally is to be of most value in smooth locations because of its penetration into the lunar surface. However, in rough terrain with rocks several wavelengths in size the subsurface data will be masked by the stronger reflections from the surface. The waveform may then reveal an average condition of the surface irregularities which are more specifically detailed in the photographs. The average values may serve statistical purposes that are incompatible with photographic methods.

Surface Geology

All of the sensing methods incorporated in the orbiter program provide some form of information about the lunar surface because they are responsive to certain characteristics of the surface material. This response is a diagnostic index, and the change in instrument response is analogous to a change in color of the material. It is unfortunate that color change cannot be used more effectively in remote geological sensing, but

surface damage from space radiation and meteorite bombardment appears to have produced extensive modification of the original color. Some color has been seen on the Moon but nothing that compares with the red spot of Jupiter or the polar cap and red deserts of Mars. The lack of lunar surface color indicates a past history of simple geologic processes and lack of variety of surface material.

Infrared experiments are an extension of color sensing. The similarity in the appearance of different rocks is often confined to the visible spectrum. Only in recent years has the reflection spectrum of rock samples been examined outside this band. Infrared photography is expected to distinguish between a few surface rock types and to delineate boundaries of layers and to show the existence of outcrops. This may be possible on the basis of chemical differences in some cases and on a basis of surface texture in others. Spectral analysis of the infrared radiation is expected to provide positive identification for a number of rock types.

The ultraviolet spectral analysis is expected to provide a similar identification capability for another group of rock types, and to serve as verification of results for the visual and infrared observations. The resolution capabilities of the ultraviolet spectrometer field of view do not permit accurate location of small sources of radiation; however, their detection within the surface area being sampled is a desired result.

The study of ultraviolet spectra of various minerals was originally stimulated by the visible fluorescent effects and old reports of this research should permit a good prediction of orbiter experiment capabilities and results.

Microwaves provide an additional capability for surface material identification. The active and passive forms of microwave study are an extension of the infrared measurements. Although no spectral anomalies are expected to provide positive identification, the emission and reflection of microwaves is associated with the electrical characteristics of the near-surface materials. These in turn are specific for certain minerals.

Experience with the microwave equipment will enhance the value of the measurements in lunar surface and near-surface work. Both microwave and infrared data will reflect the strong influence of surface temperature. The same surface will not radiate these wavelengths in the same way during predawn and afternoon Sun positions.

Natural radioactivity may be identified at orbiter altitude by the detection of the alpha, beta and gamma rays. Since beta rays have a wide range of energies and may be confused with solar wind particles, their use as indicators of radioactivity is not recommended. Both the gamma and alpha particles are to be detected in hopes that concentrations of uranium, thorium and radioactive potassium will be located. The occurrence of these elements in surface deposits will be easily detected. The implications of such deposits concerns mineral differentiation during the Moon's formative period. The existence of these deposits strongly suggests that other mineral deposits occur which may be of greater value.

Surface structure may be studied for evidence of geological process by means of the photographic maps. The stereo pairs of photographs permit accurate altitude measurements for all the prominent features. Quantitative measurements may therefore become available for studies in isostasy, folding, fracturing, vulcanism, and hypervelocity impact.

Subsurface Geology

From orbiter elevations the study of the lunar subsurface is quite restricted; however, several sensors are expected to contribute significant data. The penetration of the lunar surface by radio waves should produce the greatest detail. The measure of success in this method is not easily estimated since only marginal success has been obtained on the Earth. Water and soluble minerals have made the Earth's surface nearly opaque for radio waves and have caused complicated patterns of surface resistivity having seasonal changes which affect both the data and its interpretation. On the surface of the Moon the absence of the water and

weather will enhance the value of the method. Lunar subsurface layering is expected to influence the radio reflection waveform and to be of geological significance in a number of instances.

Photographs of the lunar surface may also reveal much concerning the subsurface. The ghost craters, which appear to have been flooded, can be identified, and subsurface structure can be anticipated from the visible structure. Similar subsurface knowledge is inferred by surface appearances of ejecta blankets or lava flows. Experience yet to be obtained will extend this capability for lunar faults, rills, domes, and mountains. Much of our experience with subsurface structure associated with surface features on the Earth may be extended to the similar lunar counterpart; however, the chain craters and impact craters, which are frequent on the Moon, are rare on the Earth and are also highly eroded.

Surface temperature has recently become an indication of subsurface geology although much study remains. The temperature is indicated with both infrared and microwave measurements. The lunar "hot spots" which are now known will be studied at closer range by the orbiter instruments. The subsurface extent of the hot spots is not expected to be great since heat from the Sun masks their activity and their influence on surface temperature. A more detailed picture of the temperature pattern of these spots may be obtained with the orbiter tests. Both microwave and infrared sensors have the capability for delineating these patterns. Further research is needed to interpret the patterns in terms of geology. The "hot spots" are best observed during an eclipse of the Moon and may not be detectable at the time of the orbiter flight. Similar heat patterns may be associated with sites of volcanic activity. The volcanic heat is not expected to be so closely related to the lunar phases or to eclipse occurrence.

Surface Geochemistry

The identification of surface minerals may result from several sensing systems as mentioned under Surface Geology. The additional information on chemical activity and processes stems from indirect

implication. Most chemical activity which is normal for the Earth is the result of oxidation, life processes, the interaction of aqueous solutions, and reactions between ions produced in the atmosphere by radiation or static electrical discharge. None of these processes find a favorable environment on the Moon. A few chemical processes associated with volcanic activity may be in evidence, and the possibility of identifying the chemicals of volcanic origin by means of their reflected infrared and ultraviolet light is quite good. Predictions concerning reactions between the chemicals which are found would be speculative. The detection of surface chemicals resulting from subsurface chemical reaction is not anticipated. The identification of trace amounts of elements and their implications is a recent development. This form of geochemistry is related to lunar atmospheric studies.

Lunar Atmospheric Measurements

Since the barometric pressure on the Moon is expected to be that of a good vacuum, the atmospheric phenomena must be considered in a revised perspective. No meteorological phenomena are anticipated and the few scattered molecules that are present do not obey the gas laws for any apparatus of feasible design. On the lunar surface a diffusion pump may be useful for increasing the atmospheric pressure to levels suitable for sample collection. In the orbiter no extensive experimental investigation has been planned.

The remote geochemical sensing experiment is designed to detect the presence of one or two specific elements above the lunar surface. The sensing is accomplished by an identification of the absorption spectrum of the specific element in question. Monatomic molecules of some of the more abundant metals are expected as a result of lunar surface bombardment and sputtering. The collection of concentration measurements will represent a new experiment with unpredictable results, and an interpretation of the fluctuations will be prepared and evaluated at some time after the mission is completed.

INSTRUMENTATION

The Programmer

Any geophysical information taken at an unknown location is of limited value and significance. It is necessary to correlate all the sensing instrument data with the cartographic mapping data in order to determine or locate the site of the geophysical measurement. The correlation is provided by automatic registration of the frame number on all films and tapes. This operation is synchronized electrically throughout the spacecraft by a programmer.

The frame number refers specifically to the photographs taken sequentially by the cartographic mapping cameras. In practice both stereo pairs of photographs should have the same number, and additionally the frame numbers would be generated for the dark side of the Moon where no photographs are possible.

This number is generated by an impulse counter. The impulse is an electric signal generated within the programmer every 10.2 seconds. Within this time the lunar surface viewed by the camera will be completely changed by the motion of the spacecraft (orbiter) and a new picture must be taken. A small overlap is provided to promote the alignment of successive photographs. Approximately 0.1 second precision is all that is required in timing the successive photographs; however, no opportunity will recur for photography of any areas (frames) which are missed. The camera shutter is actuated by the impulse and an instant later the impulse counter reading is photographically registered in the margin of the picture. The impulse actuates other counters positioned within the spacecraft for the convenience of the astronauts. In coded form the impulse counter (frame number) is recorded on the magnetic tapes for correlation with sensor data.

During the 10.2 seconds period the programmer actuates or initiates the intermediate operational phases of specific experiments. This includes changing the film to the next frame in all cameras and taking the second

pictures in 4.5 seconds for stereo imaging, and resetting the image tracking mechanism for the next view. The programmer also resets the antenna dish of the microwave spectrometer for the slant view measurement. Similar operations performed within the individual instrument installations are triggered by the programmer to provide coordination with the surface mapping or to establish time sharing between instruments using common equipment.

Photographic Investigations

High resolution lunar photographs are the principal objectives of this experiment. The orbital cameras are to provide aerial maps for use in the lunar surface studies in geodesy, geology, geography, and geophysics. There is much overlap in the objectives of lunar photographic work as presented by different groups of scientists. For example, the camera which has been used in both Mariner and Ranger space probes is well suited in many ways to the orbital experiments. Furthermore, the map requirements emphasized by several geological and geophysical groups can be met by several camera types which will have the manned orbital experiment capabilities. Similar mapping objectives and capabilities are to be found with the unmanned orbital camera flights. Fine grain film is used in cameras to obtain the finest detail or best resolution, and the astronauts are needed for the monitoring, maintenance, and direction of the photographic program. Stereoscopic photography of the Moon is an additional objective; however, it is planned to obtain the second picture of the stereo pair with a delayed photograph of the same subject. A multispectral imaging system is an additional objective. This is a set of photographs made with different types of film and spectral filters to bring out differences in surface material which are revealed by color and by infrared and ultraviolet reflectance or emission.

Photographic equipment may be available for lunar mapping as off-the-shelf hardware. The requirements for the orbiter cameras are similar to those of aerial mapping cameras and photo reconnaissance

equipment⁴. Typical specifications are presented in the following example in which assumed values for the film resolution and the desired map scale for the photographic negative will approximate the flight requirements.

Film: 70 mm frame with 200 line per mm resolution

Photograph Scale: 1:200,000

Lens: focal length = 41 cm
diameter = 53 mm
f/ = 8

Field: 14 km at 81.5 km range
resolution = 1 m

For actual orbiter operation a lens of higher light gathering capability than f/8 is recommended. This is necessary to maintain the desired optical resolution at longer wavelengths (red) and to provide sufficient exposure of the film when using spectral filters or short exposure times.

To provide stereopticon pictures of the lunar surface, two pictures of the same area must be photographed with a difference in their angle of view. Since surface objects appear to pass beneath the orbiter with an angular velocity of 1.1 deg/sec, a parallax angle of 5 degrees is provided if the second picture is photographed 4.5 seconds later. An image tracking mechanism is desirable to facilitate this operation and to provide a similar function for several other radiation sensors.

The image tracking mechanism suggested is a rocking frame which supports all the cameras and radiation sensitive detectors. It serves to aim these instruments at the same point on the lunar surface for 10.2 seconds and thereby to compensate for the rapid motion of the spacecraft. Since the high resolution photographs portray objects as small as 1 meter, image smear will occur with exposures as short as 0.00064 second without the compensation. It is additionally recommended that focal plane shutters

be used to help prevent image blurring. Other methods of improving the image quality may be recommended after further study. The mechanical follower is recommended for the radiation detector equipment which may operate with scan times or effective exposure times of many seconds. One embodiment of the desired image tracking mechanism consists of a rectangular frame which is permitted to rotate about a horizontal axis. The angular position is held by a cam which is turned at a constant speed. This provides a constant angular speed for the frame. At the moment the cam completes one turn the frame quickly returns to its original position. All the instruments are aimed in this moment at a new lunar surface area. This action must be synchronized with the instrument programmer described in the previous section. The high resolution cameras operate twice as often as the multispectral cameras.

Multispectral photographs require additional camera and film systems which operate simultaneously. A nine-lens camera has been used by the University of Michigan to collect multispectral imagery between 3,000 and 14,000 Å. Each lens is associated with its own filter and film⁵. At the University of California several cameras have been used incorporating six different combinations of film and filter to collect multispectral imagery between 4800 and 9700 Å (Reference 6). The use of five of these spectral channels is recommended for the orbiter. A chart is presented in Table 2 which lists the filter, the film type, and the spectral zone of sensitivity for each of the five cameras. Their field of view is 22.4 degrees to permit contiguous overlap of coverage by successive orbital passages.

The compatibility of the photographic experiments is related strongly to the spacecraft stability. The Apollo capability of 0.5 degree attitude control is sufficient for aiming the cameras if a slight overlap is provided between adjacent frames. To prevent blurring of the 1-meter objects recorded on the film during an exposure of 1/50 second the spacecraft angular velocity must be less than 0.035 deg/sec. This value is

TABLE 2
MULTISPECTRAL IMAGERY USING FIVE CAMERAS

Camera Number	Film Type	Spectral Filter	Sensitivity Band (Wavelength - microns)	Color
1	Panchromatic	Wratten 12	0.48-0.72	Yellow White
2	Panchromatic	Wratten 47B	0.33-0.49	Violet
3	Panchromatic	Wratten 61	0.47-0.62	Yellow Green
4	Panchromatic	Wratten 90	0.56-0.72	Orange
5	Infrared	Wratten 89B	0.71-0.96	Infrared

slightly beyond the Apollo stability capability; however, it is expected that the angular velocity will be acceptable most of the time.

No view finder has been incorporated into the design or operation of the photographic mapping program. The generation of the sequence of photographs along the flight path requires no viewing or aiming. A photometer is provided to enable the astronaut to make aperture adjustments. This would be most valuable if several orbits are progressively crossing the terminator while flying nearly parallel with it. A suborbiter surface picture is available from the coherent imaging radar. This may be used as a view finder. A wider range, side-looking radar should present a lunar surface picture in a more familiar perspective and scale of magnification.

A pattern for photographic mapping is associated with a schedule for turning the cameras on and off at specific points in each orbit. If continuous operation of the cameras is permitted, then the polar regions would be duplicated 99 times while photographing the lunar equator only once. A 25% reduction in film weight is realized with the mapping pattern indicated in an expanded form of the polar view in Figure 2. The pattern is more specifically presented in Table 3. It is noted here that a polar crossing must be photographed four times. This schedule provides for contiguous or overlapping photographs of all the area beneath the orbiter. During "on" time for the cameras, the orbiter will travel 425,710 km. For a map scale of 200,000:1 the high resolution pair of cameras will use 8.514 km of film for stereo pair photographs. This weighs 110.8 lb. For a multispectral imaging camera the map scale is 400,000:1 and the reproduction is not stereo. This uses 1.065 km of film for each of the five for a total weight of 69.2 lb. This weight is to be returned to Earth. If this mapping schedule is to be automated, an orbit counter should be incorporated in the design of the programmer. The orbit count may be sensed by the inertial guidance attitude control or by a sunlight sensitive photo cell. Lunar latitude may also be determined by these two methods.

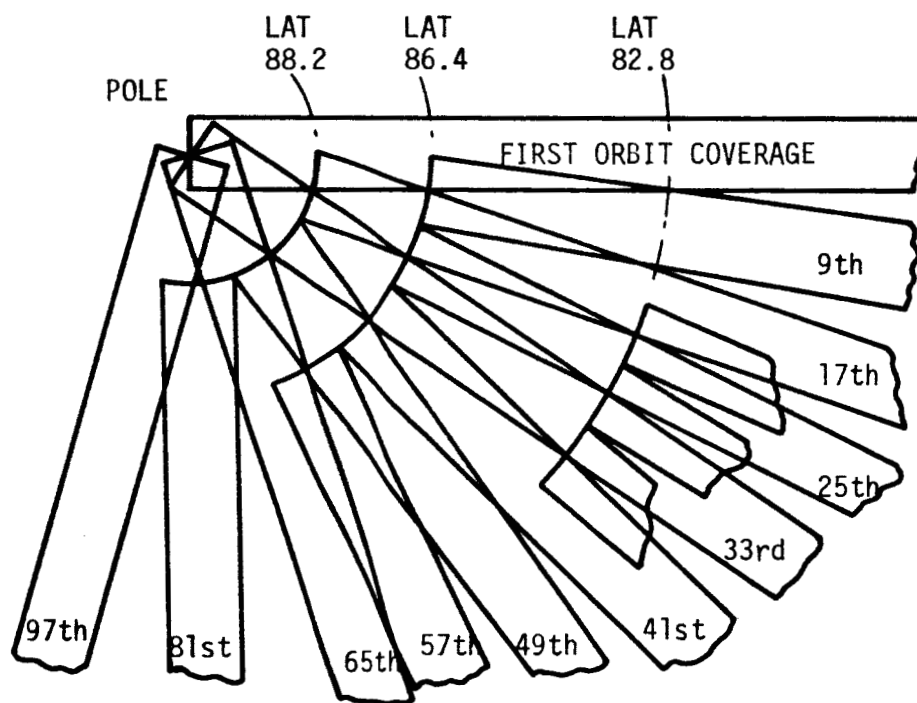
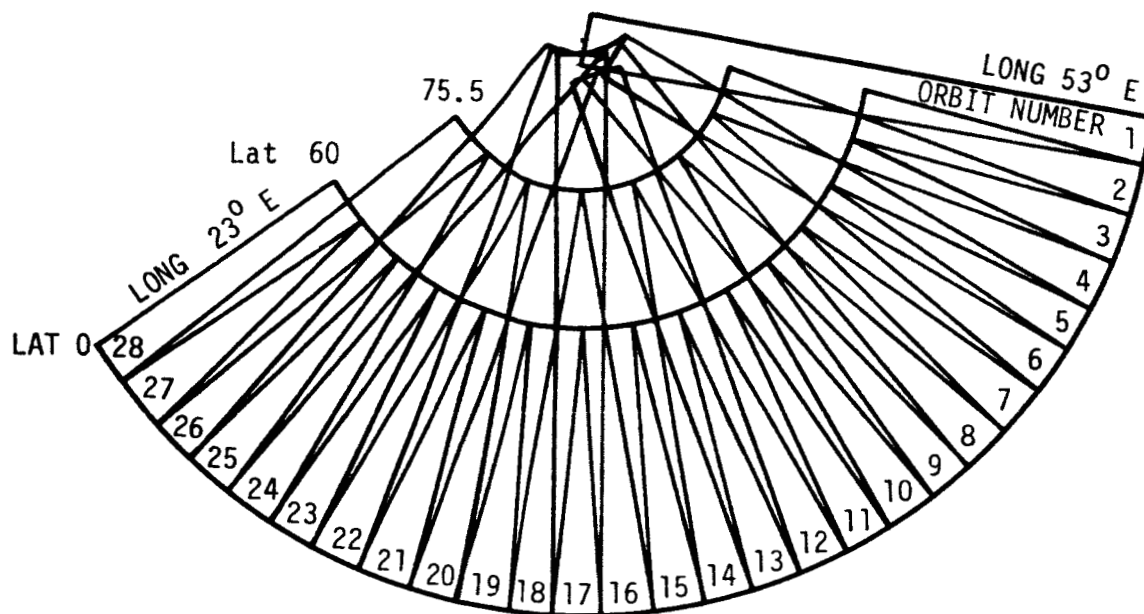


Figure 2. Polar View of Part of Photographic Mapping Pattern

TABLE 3
CAMERA SCHEDULE

<u>Orbit Numbers</u>	<u>Start Camera Lat N Stop Camera Lat S</u>	<u>Orbit Numbers</u>	<u>Start Camera Lat N Stop Camera Lat S</u>
1	90°0'	41	86°4'
2	60°0'	42	60°0'
3	75°5'	43	75°5'
4	60°0'	44	60°0'
5	82°8'	45	82°8'
6	60°0'	46	60°0'
7	75°5'	47	75°5'
8	60°0'	48	60°0'
9	86°4'	49	88°2'
10	60°0'	50	60°0'
11	75°5'	51	75°5'
12	60°0'	52	60°0'
13	82°8'	53	82°8'
14	60°0'	54	60°0'
15	75°5'	55	75°5'
16	60°0'	56	60°0'
17	88°2'	57	86°4'
18	60°0'	58	60°0'
19	75°5'	59	75°5'
20	60°0'	60	60°0'
21	82°8'	61	82°8'
22	60°0'	62	60°0'
23	75°5'	63	75°5'
24	60°0'	64	60°0'
25	86°4'	65	90°0'
26	60°0'	66	60°0'
27	75°5'	67	75°5'
28	60°0'	68	60°0'
29	82°8'	69	82°8'
30	60°0'	70	60°0'
31	75°5'	71	75°5'
32	60°0'	72	60°0'
33	90°0'	73	86°4'
34	60°0'	74	60°0'
35	75°5'	75	75°5'
36	60°0'	76	60°0'
37	82°8'	77	82°8'
38	60°0'	78	60°0'
39	75°5'	79	75°5'
40	60°0'	80	60°0'

TABLE 3 (Continued)

<u>Orbit Numbers</u>	<u>Start Camera Lat N Stop Camera Lat S</u>	<u>Orbit Numbers</u>	<u>Start Camera Lat N Stop Camera Lat S</u>
81	88°2'	91	75°5'
82	60°0'	92	60°0'
83	75°5'	93	82°8'
84	60°0'	94	60°0'
85	82°8'	95	75°5'
86	60°0'	96	60°0'
87	75°5'	97	90°0'
88	60°0'	98	60°0'
89	86°4'	99	75°5'
90	60°0'		

NOTES:

- Travel time from pole to: 90°0' - 0 min
88°2' - 0.583 min
86°4' - 1.167 min
82°8' - 2.333 min
75°5' - 4.667 min
60°0' - 9.667 min
- For each orbit tabulated, the lunar latitude is given for starting the cameras. The cameras are stopped at the same latitude on the other side of the equator. During operation the high resolution cameras take a picture each 10.2 seconds. Multispectral cameras take a picture each 20.2 seconds.

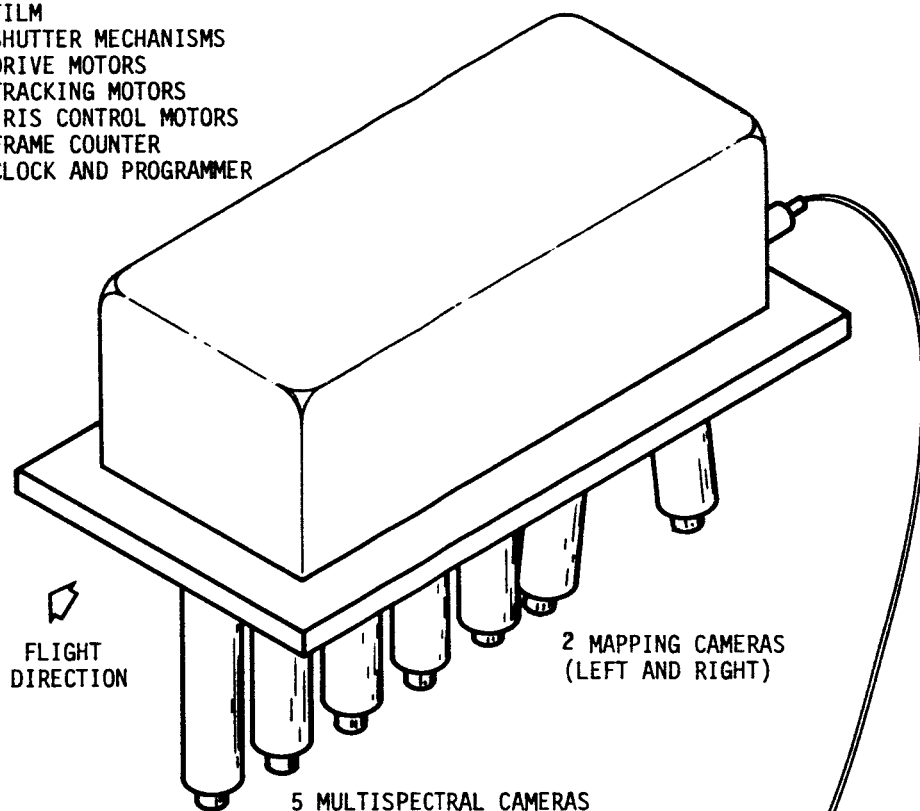
Figure 3 represents a conceptual configuration of the photographic equipment for stereo mapping with high resolution and simultaneous spectrophotometric recording with approximately half the resolution of the mapping cameras. It is probable that the cameras will be mounted in a place which is inaccessible to the astronauts, and provision is made for remote control and monitoring of the photographic process.

Infrared Surveying

As an extension of the multispectral photograph experiments, the infrared surveying tests will provide surface temperature measurements and surface IR emittance data for the lunar surface. An accurate determination of the chemicals present in the lunar materials is not presently feasible because surface roughness or grain size and the effects of viewing angle are factors which reduce the quality of the infrared spectral data⁷. Some success, however, has been attained in this effort and possibilities are quite good for obtaining calibration data and rock sample spectrograms in the near future which will serve to identify a large number of the lunar rock types. It is expected that large areas of Moon surface will have the same surface material and that the optics of the infrared sensors will not need the high resolution capabilities of the multispectral imagery equipment.

On the Earth the thermal methods of geophysical prospecting have never been considered practical because of the prominent influence of water, weather, sunshine, and evaporation. Only when thermometers can be placed in dry holes of sufficient depth to avoid surface effects will the geological influence on the thermal gradient of the Earth appear. Temperature measurements at the bottom of most oil wells have been recorded for use by drillers and reservoir engineers; however, no geophysical application has been found for this data. By analogy it is difficult to anticipate the results of lunar surface temperature mapping. The effect of geology on the lunar observations is expected to be more prominent because of the absence of the usual extraneous influences. The lunar

FILM
SHUTTER MECHANISMS
DRIVE MOTORS
TRACKING MOTORS
IRIS CONTROL MOTORS
FRAME COUNTER
CLOCK AND PROGRAMMER



FLIGHT
DIRECTION

2 MAPPING CAMERAS
(LEFT AND RIGHT)

5 MULTISPECTRAL CAMERAS

WEIGHT: 688 lb
VOLUME: 20 ft³
POWER: 25 W

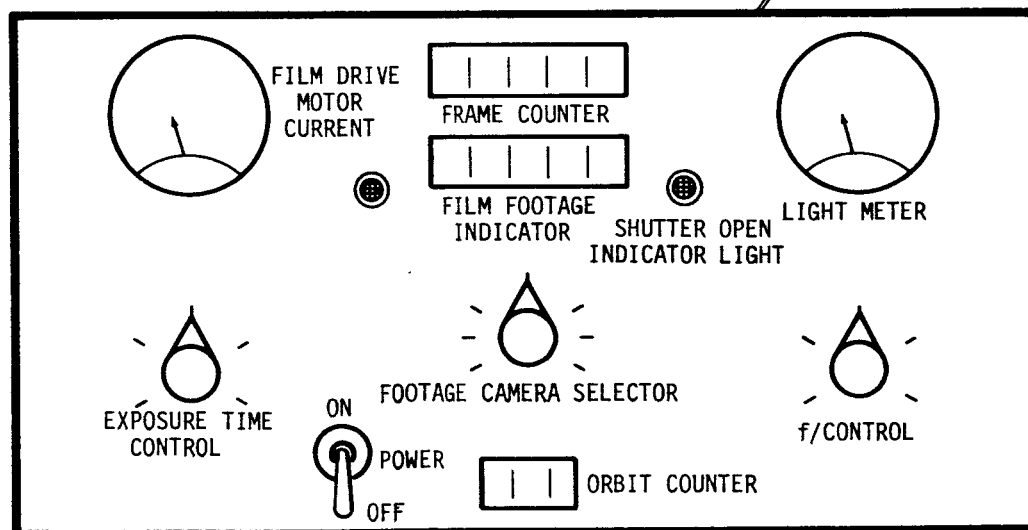


Figure 3. Cartographic and Multispectral Imagery Equipment

"hot spots" which have already been found by infrared measurement are not completely understood. They are prominent only during a lunar eclipse and appear as places which cool slowly rather than as sources of heat. In either case an associated geological anomaly is expected. Infrared experiments have been fruitful in a few shallow geophysical problems⁵. Ice thickness is revealed by infrared intensity, and thermal mapping has been done at Yellowstone Park and at an active volcano site in Hawaii.

Infrared scanning has been successfully instrumented in space applications. A high resolution infrared radiometer is the single channel scanning instrument built by ITT Industrial Laboratories for the Nimbus I weather satellite. The radiometer incorporates a photoconductive cell of lead selenide (PbSe) and is made sensitive in the 3.4 to 4.2 micron region of the infrared spectrum by a filter in the optical path. The radiometer, which weighs 11.3 lb and requires 4 W, can sense temperatures in the range 210°K to 330°K. The combined Newtonian and Gregorian optics⁸ provide 1/2 degree resolution which is 0.7 km for the orbiter height of 81.5 km. The scanning rate is 45 per minute which generates an information bandwidth of 280 Hz. Within the atmospheric window used by this instrument the best operation was obtained at night when no reflected radiation was present from the Sun⁹. A medium resolution radiometer has also been designed for the TIROS satellite. The instrument has about the same size, weight, and power and is capable of sensing the entire infrared spectrum from 0.2 to 30 microns. With its wider angle of resolution, 2.85 degrees, its scanning rate is 8 per second. Both types of IR radiometers can be adapted to tape recording. The high resolution instrument requires a tape speed of 3.75 in./sec. The faster scanning system may require a higher speed tape¹⁰. A time signal is normally recorded simultaneously on an adjacent channel on the same magnetic tape; however, in the orbiter experiment the frame counter number from the photographic mapping apparatus would be desired. A continuous tape of

the 99 lunar passages would have a length of 217,000 ft and would weigh 942 lb. For this reason the tape data will be transmitted to Earth by radio and the tape will be erased and used again. Direct transmission of data to Earth without tape is not possible since much of the data will be sensed on the farside of the Moon.

Two figures are presented illustrating the radiometer. Figure 4 shows the optical system and Figure 5 is a graphical form of the electrical output signal. This waveform should be available to the astronauts by means of an oscilloscope for monitoring the radiometer operation. Figure 6 shows a monitor and control panel which is recommended to permit supervision of the recording operation by the astronauts for a radiometer which is mounted in an inaccessible location.

A second infrared sensing device for lunar surface surveying is designed to provide a spectral analysis of the radiation. The general form of this spectrogram is related to surface temperature, surface texture, and color. Specific anomalies in the spectrogram are related to the minerals present at the lunar surface⁷. The instrument is an interferometer of the Michelson type with a movable mirror. The instrument is illustrated schematically in Figure 7 as it appears in Reference 10. The displacement of the mirror determines infrared wavelengths which reach the thermistor detector. For weather satellite operation this instrument covers the IR band from 5 to 20 microns. This band is repetitively scanned by successive triggering of the mirror drive mechanism. The interferometer is used in conjunction with suitable telescope optics to establish a field of view of about 5 degrees⁸. A tracking mechanism similar to that of the photographic mapping is required to provide a fixed source of lunar surface radiation during the time that the spectrogram is being recorded. For the particular instrument described this spectral scan time is 11 seconds although a more sensitive detector may be found which would permit a faster scan.

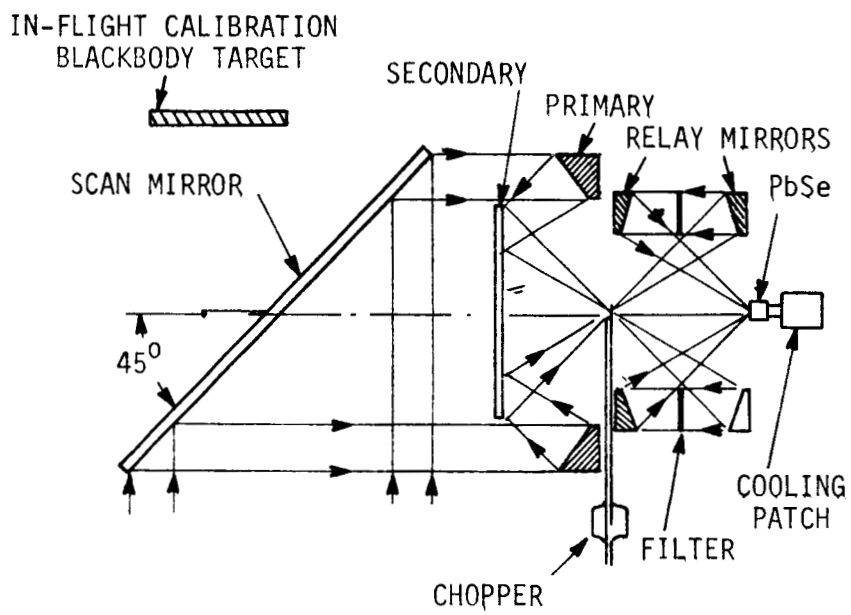


Figure 4. Schematic of the HRIR Optical System

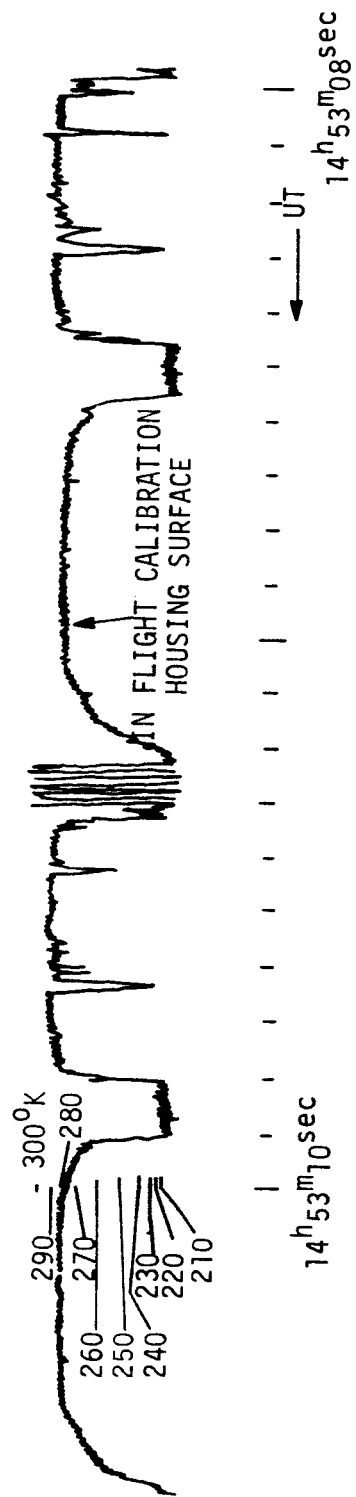


Figure 5. Portion of an Analog Record Showing Nearly Two HRIR Scan Cycles

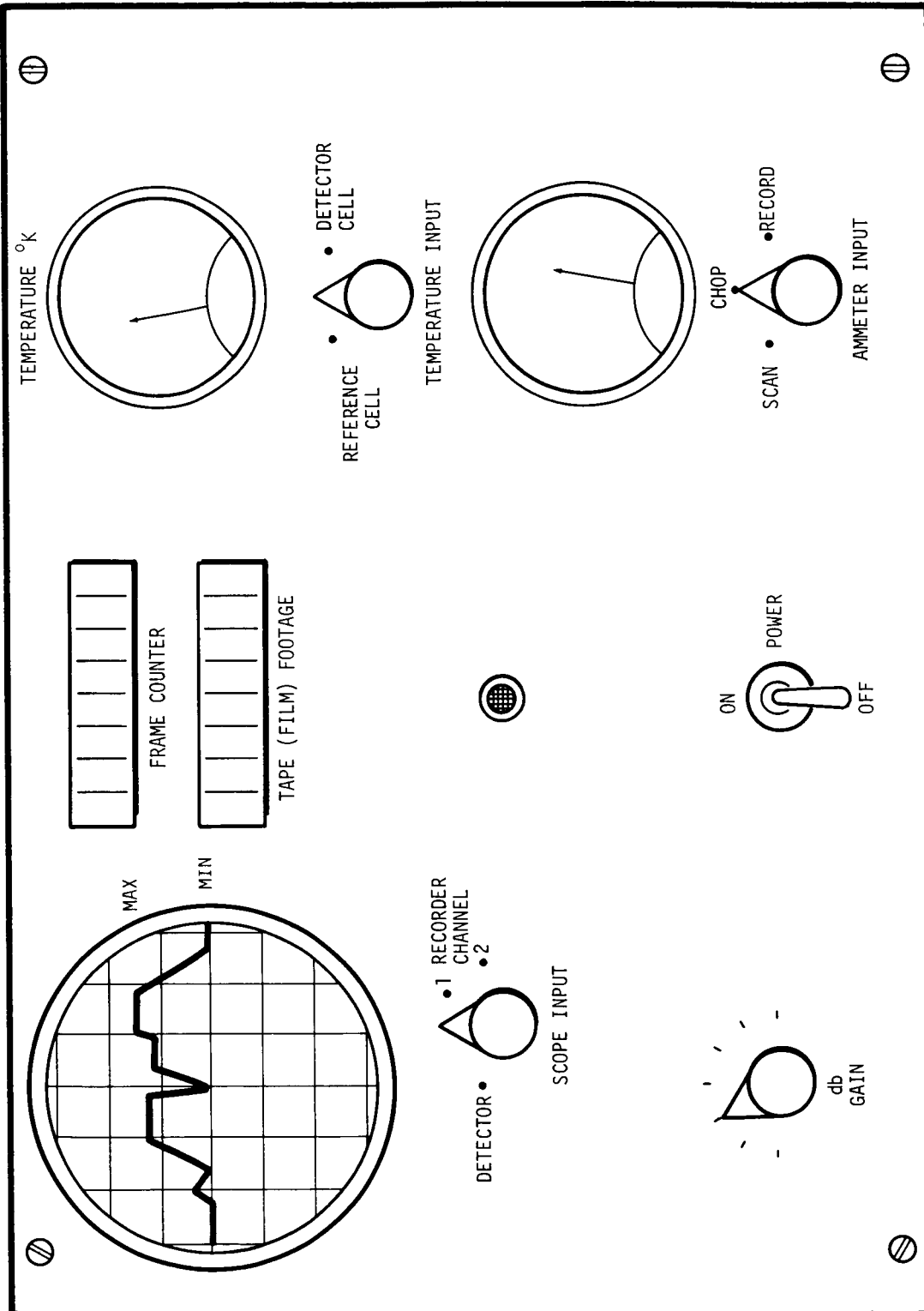
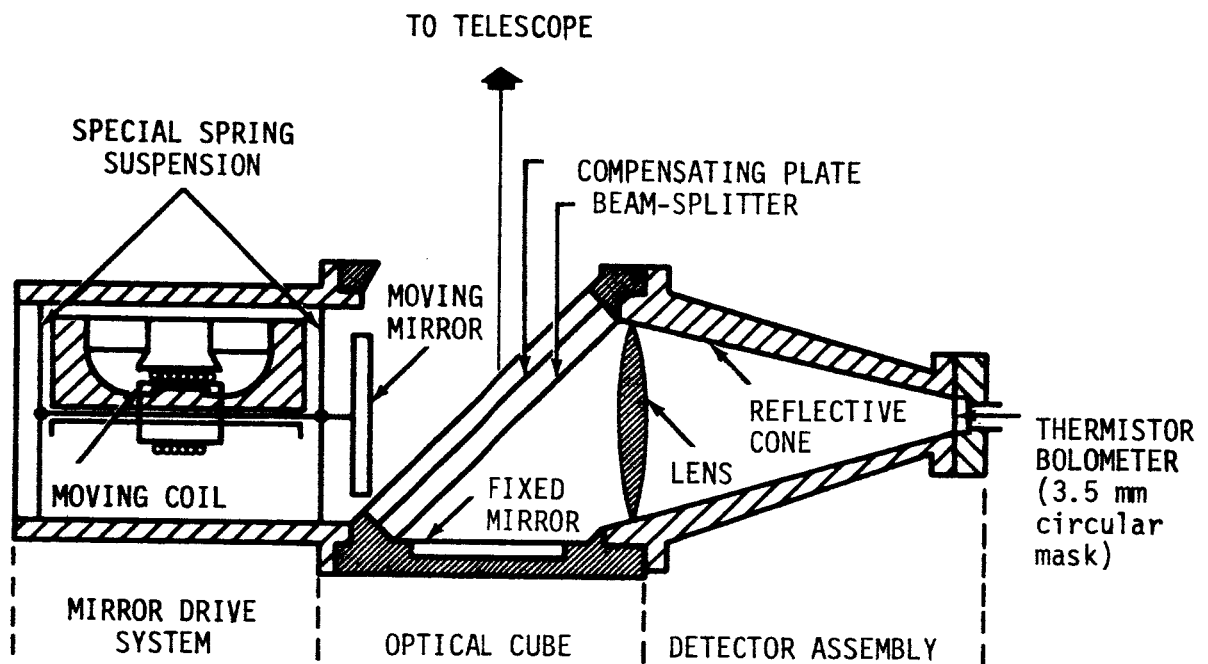


Figure 6. Monitor and Control Panel for Infrared Radiometer



Neon Light Source and Auxiliary Detector for 5852
Reference Line Not Shown

Figure 7. Interferometer Cube, Mirror Drive Assembly, and Detector Assembly, Schematic Diagram (From Reference 10)

Magnetic tape recording is also recommended for the IR spectrometer. With the slower scan rate the interferometer will not require the tape speed used in the radiometer. Approximately one-tenth of the tape speed and tape quantity is estimated as sufficient.

Alternate methods are possible for recording infrared spectra. Prisms of special material (NiCl) are used to form the spectrum in the infrared band. Diffraction grating instruments are also used. Further study may indicate a desirability for one of these alternatives.

Passive Microwave

These experiments require only radar receivers. The radio wavelengths are between 1 mm and 20 cm and the usual antenna dish is effective in forming a narrow beam of good radio reception. Microwave noise is received when this beam is directed toward a warm surface, and the electrical power in the antenna due to this noise is proportional to the surface temperature. Equivalent power in the radar receiver may be obtained from a resistor which is connected to the receiver in place of the antenna. This is done as a means of calibrating the receiver's sensitivity to microwaves. To be used as a radiometer the receiver output noise is converted to dc and is averaged for about 1 second. The average is a voltage of suitable form for magnetic tape recording. In lunar orbiter application the frame number of the cartographic camera operation would be recorded on an adjacent tape channel.

Microwave sensing has been studied extensively in only the last few years. The absorption of these waves by the atmosphere led to the use of microwaves in atmospheric studies¹¹. The advent of satellite communication has led to equipment development for space stations and orbiters¹². As a radiometric sensing method the microwave radiometer has been of the most interest to military and aerospace research teams^{5, 12-15}. The applications include missile guidance, horizon sensing, sea state evaluation, snow depth and ice thickness measurement, and iceberg detection in addition to the atmospheric studies. A

summary of these activities is presented in the chart of Table 4 which may be found for 1964 in Reference 12. For the lunar surface no atmospheric effects are expected, and all microwave signals (noise) are characteristic of the lunar surface. The data recorded represents an extension of the infrared experiments. The longer wavelength of the microwaves is expected to be associated with increased depth into the lunar surface. As a result, the microwave intensity is presumed to remain unaffected by lunar surface film or by thin dust layers. The emissivity of the surface for microwaves is related to the surface temperature and also to the dielectric constant and to the resistivity of the surface materials. These factors are expected to produce additional contrast between microwave and infrared maps.

Microwave Imagery - The use of a single passive radiometer with a rapid antenna scan capability will permit a microwave picture or lunar surface image to be formed. With an antenna aperture of 6 ft (1.8 m) in the X-band, a resolution of 4.75 km may be obtained. If sufficient bandwidth is available, the microwave intensity level may be scanned with one-half the rate of the infrared imaging experiment. This scan rate of 23 per minute is sufficient for the beam resolution mentioned. About one-half the tape speed of the infrared recorder is sufficient for the microwave data.

The possibility of stereo imagery has been suggested¹⁴. This may be accomplished by repeating the microwave image of the same lunar surface area as seen from another point along the orbiter trajectory. This method is to be used in the cartographic camera experiments. To obtain 5 degrees of parallax between the stereoscopic images, the images must be produced 4.5 seconds apart. This time is derived from the orbiter height and velocity considerations. If the orbit is not exactly circular, then some variations in this time will be found. This delay between images is feasible for cameras with short exposure times; however, the infrared and microwave scanning systems are too slow. Several

TABLE 4

REPRESENTATIVE MILLIMETER RADIOMETRIC PROGRAMS (1964)

Organization	Frequency Regime (wavelength - cm)	Type Measurements
Space-General Corp.	0.1 cm, 0.21 cm, 0.43 cm, 0.85 cm, 1.8 cm, 2.3 cm, 25-30 cm	Aircraft Flight Test - gradient mapping - land-water boundaries - snow data - ice data - precipitation data Ground Tests - terrain materials - apparent temperature - cooled and heated bodies - apparent temperature - freezing water data - snow data - ice data - sky temperature - atmospheric data
Bell Telephone Laboratories	0.86	Ground Tests - terrain materials - detailed apparent temperature - sky background - average readings - rain, snow effects - scanning - radiometer pictures
Cambridge Research Center	0.86, 1.25, 2.2 3.2	Aircraft Flight Tests - mapping (0.86, 1.25, 3.2 cm) propagation and atmospheric Ground Measurements - terrain materials (1.25 cm)

TABLE 4 (Continued)

Organization	Frequency Regime (wavelength - cm)	Type Measurements
Coast Guard	3.0	Aircraft Flight Tests - detection of icebergs
E. E. Laboratory (University of Texas)	0.16, 0.215, 0.27, 0.32, 0.43, 0.5	Ground Tests - terrain materials - detailed apparent temperatures (0.43 cm)
		Propagation and Atmospheric
Ohio State University	0.86, 1.8, 0.86	Radiometer, Radar Theoretical Work Radar Ground Tests - terrain materials (0.86, 1.8, 0.86 cm)
Royal Radar Establishment	0.86	Aircraft Flight Tests - mapping absolute temperatures - some snow readings
Sperry Gyroscope	1.8, 3.3	Aircraft Flight Tests - mapping, high resolution, pri- marily land-water boundaries
University of Wisconsin	3.3	Aircraft Flight Tests - qualitative terrain gradients, some ice and snow
Wiley Electronics	3.3	Aircraft Flight Tests - qualitative mapping, high resolution

seconds are required to produce the data for a single image. There is also some doubt about the quality of the images in terms of stereo reproduction. The resolution of the microwave detector is expected to be several kilometers and only the highest mountains or deepest valleys will be apparent. In addition there are extraneous factors in microwave intensity due to the polarization of the detected waves and to the angle of view. These factors are not expected to be apparent at 5 degrees variation in viewing angle, but may prevent good stereo images at larger parallax. Stereo imaging is not recommended for Flight 511 but is postponed until an improved technique is feasible.

Microwave Spectroscopy - It is planned to record the microwave noise generated at the lunar surface for six different frequencies with two planes of polarization and two angles of viewing. On a subsequent orbital flight a repeat measurement is desired with a different solar angle. These variables which are to be recorded on the magnetic tape on an adjacent channel serve to isolate effects of surface roughness on the observed microwave intensity. Additionally the distinction is emphasized between surface reflected microwaves and surface generated microwaves. The effects on the intensity due to subsurface anomalies is more strongly accentuated. To obtain all of these measurements, an incomplete or discontinuous coverage of the lunar surface is planned.

The wavelengths of 0.4, 0.8, 1.6, 3.3, 7, and 21 cm are desired spectral samples. Since each will have different beam widths, the sensitivity of the radiometer will change accordingly and two similar systems are recommended to provide an adequate dynamic range of recording capability for the anticipated values of emission intensity. The beam axes for the two dishes are made parallel, and provision is made in the dish mountings for sequentially aiming them downward and then 60 degrees forward along the orbiter flight path. With superheterodyne receivers in each radiometer the desired wavelength may be selected by an appropriate local oscillator. The block diagram of Figure 8 illustrates one of the

radiometer systems with provisions for 3 outputs representing microwave intensities at 3 different wavelengths. Figure 9 is a suggested panel to provide remote monitoring and control capability when the apparatus is mounted in an inaccessible position.

Radio Reflectivity

This method of sensing lunar surface characteristics employs a radar ranging system. A directional antenna system is employed for transmitting a radio wave downward from the orbiter, and for reception of the associated echo from the lunar surface. A wavelength near 1 m is planned which is too long for the practical construction of a highly directive antenna which is small enough to be carried in the orbiter. Since the beam is not narrow, the lunar surface resolution is not good enough to employ scanning methods, and no surface imagery technique is planned. The echo is expected to be the radiation due to specular reflection at the lunar surface from a point located directly below the orbiter if the lunar surface is flat. The travel time of the echo is normally employed to determine distance. This process will be employed only if the radar altimetry unit fails. Of greater importance is the waveform of the echo. This impulse is to be recorded for future study and analysis as an indicator of subsurface geological anomalies.

The use of the radio echo as a lunar subsurface sensing method is feasible for two reasons. First is the comparatively long wavelength of the radio wave. A surface penetration of several wavelengths is much deeper for meter long waves than for centimeter or millimeter wavelengths. The second reason is the transparency of the lunar surface. The lack of water on the Moon makes the surface conductivity much lower than that of our Earth. The dielectric constant of the lunar rocks provides a high reflection coefficient for incident radar waves but does not cause strong absorption of the wave energy which penetrates the surface. The underground wave may therefore reflect and return from any subsurface interfaces of rock types having contrasting electrical properties. If the wave transmitted

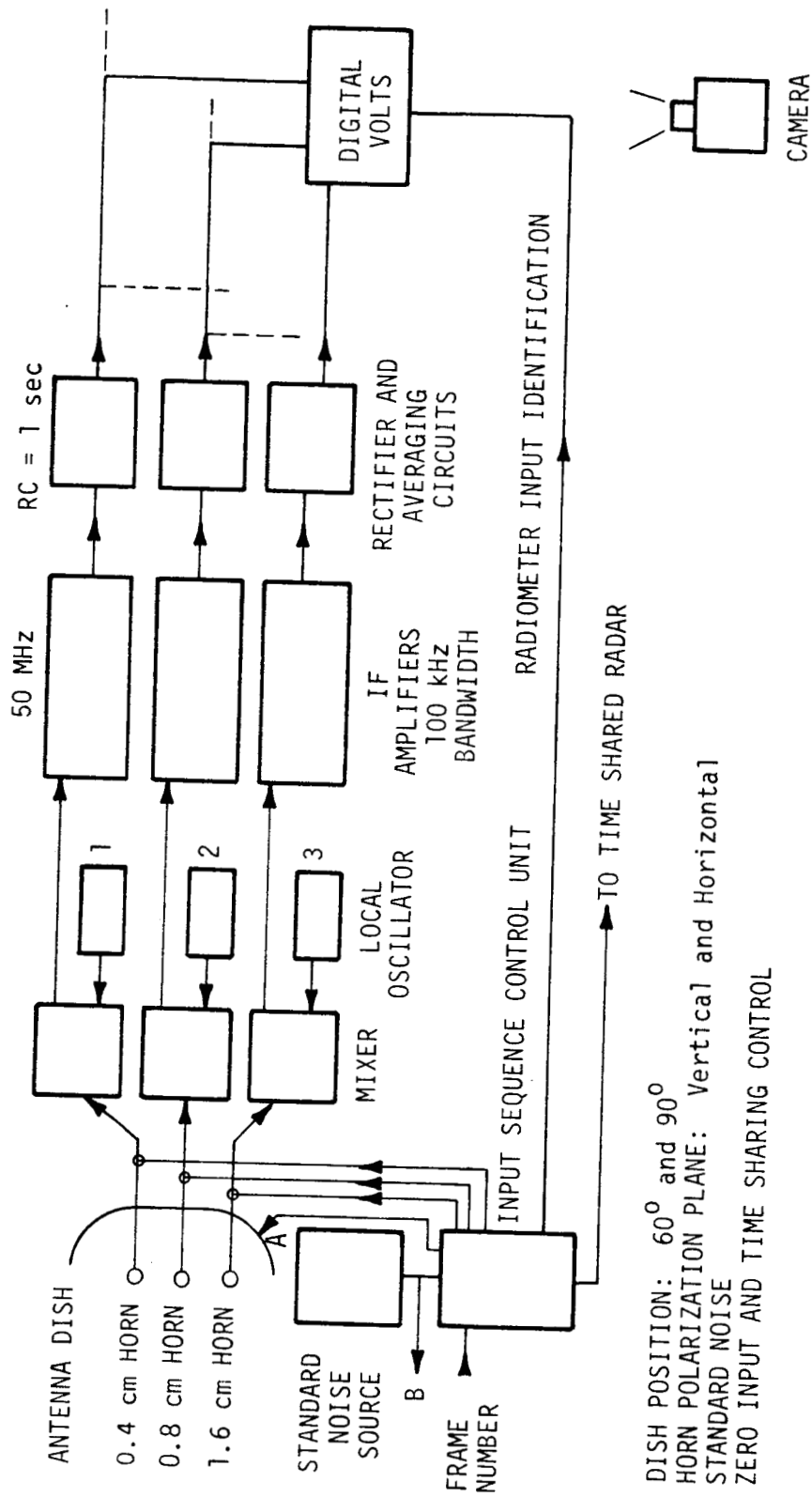


Figure 8. Block Diagram of Microwave Spectrometer
(Radiometer B requires different size dish and horn assembly.)

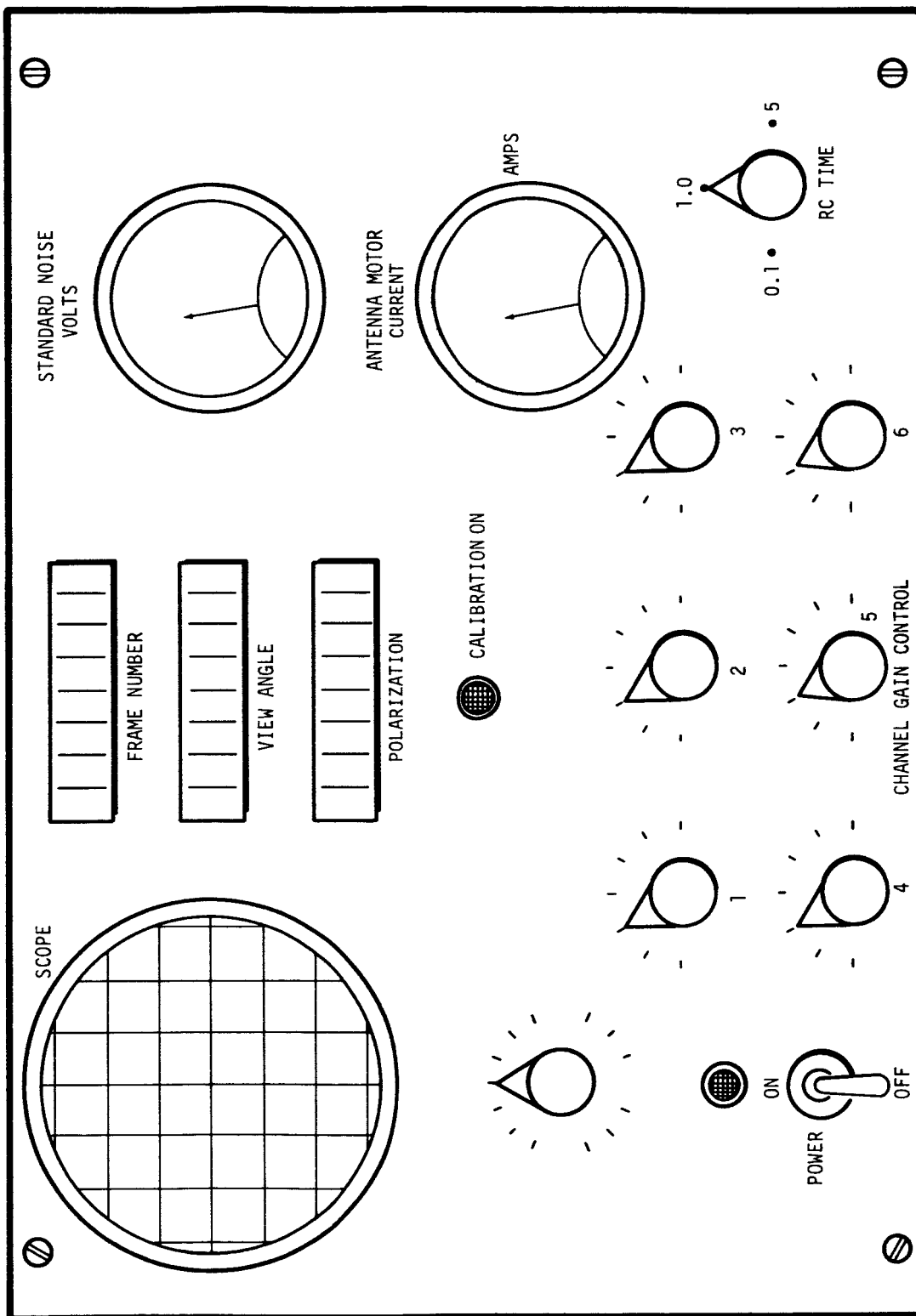


Figure 9. Monitor and Control Panel for Microwave Spectrometer Systems

from the orbiter is an impulse of short duration, the echo waveform is a time series of pulses representing the geological sequence of reflecting layers. The magnitude of these pulses is related to the contrast in the rock properties. It is believed that ice deposits and several types of ore will have sufficient contrast to permit their location and identification by satellite echo observations. The surface reflection coefficient which is indicated by the first pulse of the series is diagnostic of the surface rock even in the absence of any additional pulses.

Equipment for radio reflection sensing is on hand. The radio altimeter has been used on aircraft for many years. The electronic equipment is accordingly designed for high reliability, low power consumption, and small size and weight. Since the echo waveform is not needed in radio altimetry, this system does not include the desired echo recording capability.

The real-time tape recording of microwave impulses is not recommended. For compatibility with other experiments, a tape speed below 7-1/2 in. /sec is desired. Therefore, a waveform sampling technique is suggested as a means for regenerating the echo waveform within the frequency band of conventional magnetic tape recorder capabilities¹⁶. A sampling oscilloscope has the desired capability of time-scale expansion.

The echo waveform is influenced not only by the lunar surface but also by the waveform transmitted from the orbiter. A pulse of high peak power is desired to provide greater depth penetration into the lunar surface. A pulse of short duration is needed to give good resolution of the individual impulses which comprise the echo waveform. An alternate waveform used in radar is called a chirp. This is a pulse of longer duration but with a progressive drift in the frequency of the emitted wave. The chirp waveform is a suitable alternative for the lunar orbiter instrument.

Time sharing for this apparatus must be given serious consideration. It is necessary to prevent the transmitted chirp or impulse from appearing in the output of the passive microwave sensing apparatus. Even though the two types of radar experiments are not operating in the same spectral band, it may not be possible to provide sufficient isolation by means of tuning and filtering. If cross-talk occurs, the active radar reflection experiment will generate an error in the microwave temperature measurements. This problem may be resolved by use of the microwave spectrometer input sequence control illustrated in Figure 8. Since active radar measurements require less than 0.1 second to generate the echo waveform many times, it is advisable to operate only during the time that the two spectrometer systems are recording the internal standard noise signal. During this moment of calibration recording, the spectrometers cannot detect the radiation from the radar altimeter transmitter. Since the radar antenna is not highly directive, a continuity of operation may be sacrificed.

Figure 10 presents a block diagram of the radio reflectance recording system. Since a similar diagram also describes the radar altimetry, an echo timing block is included with an elevation data input to the recorder. This is a desirable capability for both sensing systems. Figure 11 illustrates the control.

Radar Reflectance, Imagery and Altimetry

With similar objectives and capabilities, this radar altimetry equipment extends the spectral range of the radio reflectance measurements, and provides another surface imaging method. The two wavelengths, 3.75 cm and 75 cm, are shorter and, therefore, may be directed into a narrow beam with higher capability of resolution for lunar subsurface interfaces. The short wavelengths may have reduced capability of depth penetration, and the value of the data is related therefore more strongly to the study of lunar material surface effects. The echo pulses may be

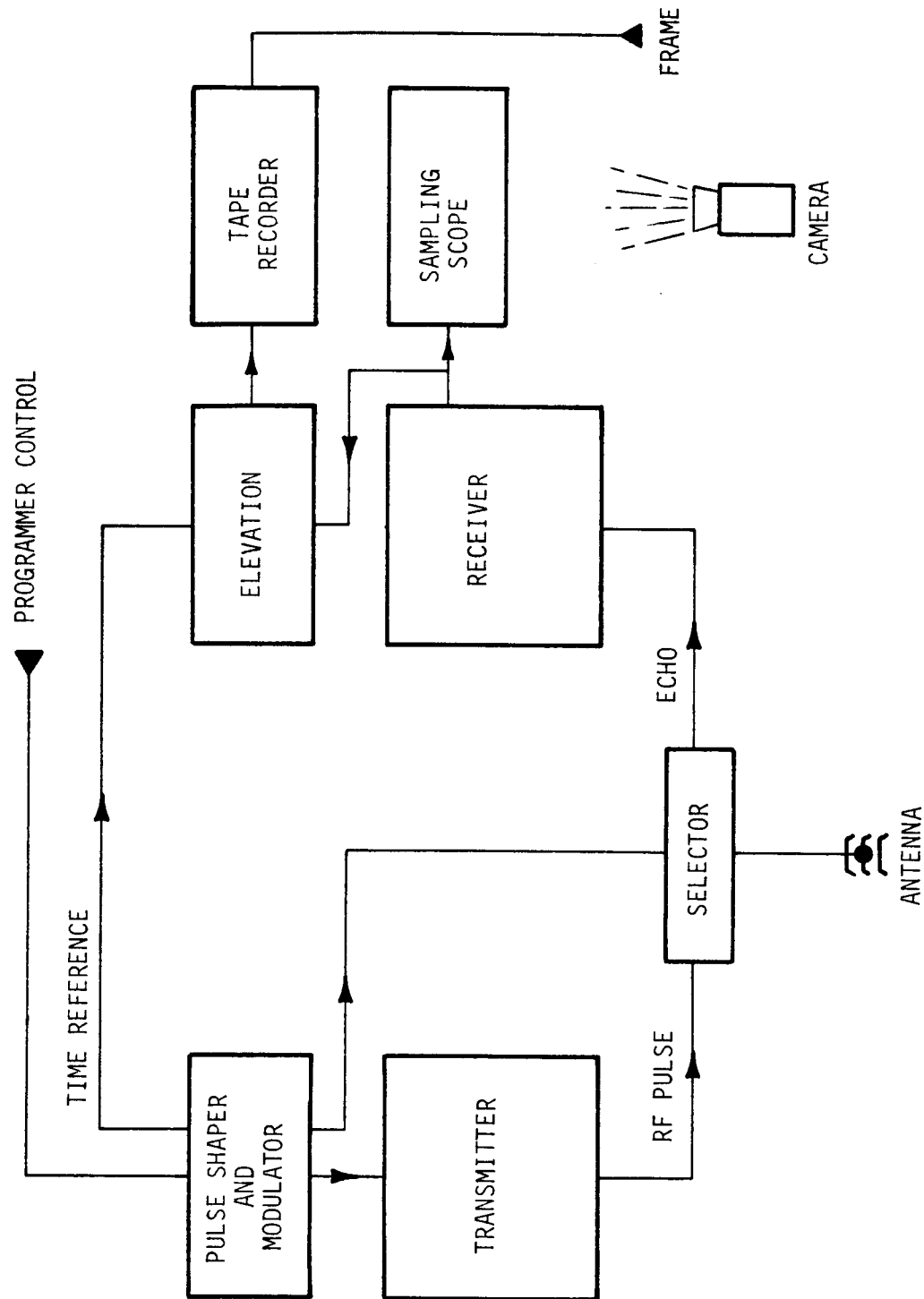


Figure 10. Block Diagram of Radio Reflectometer System

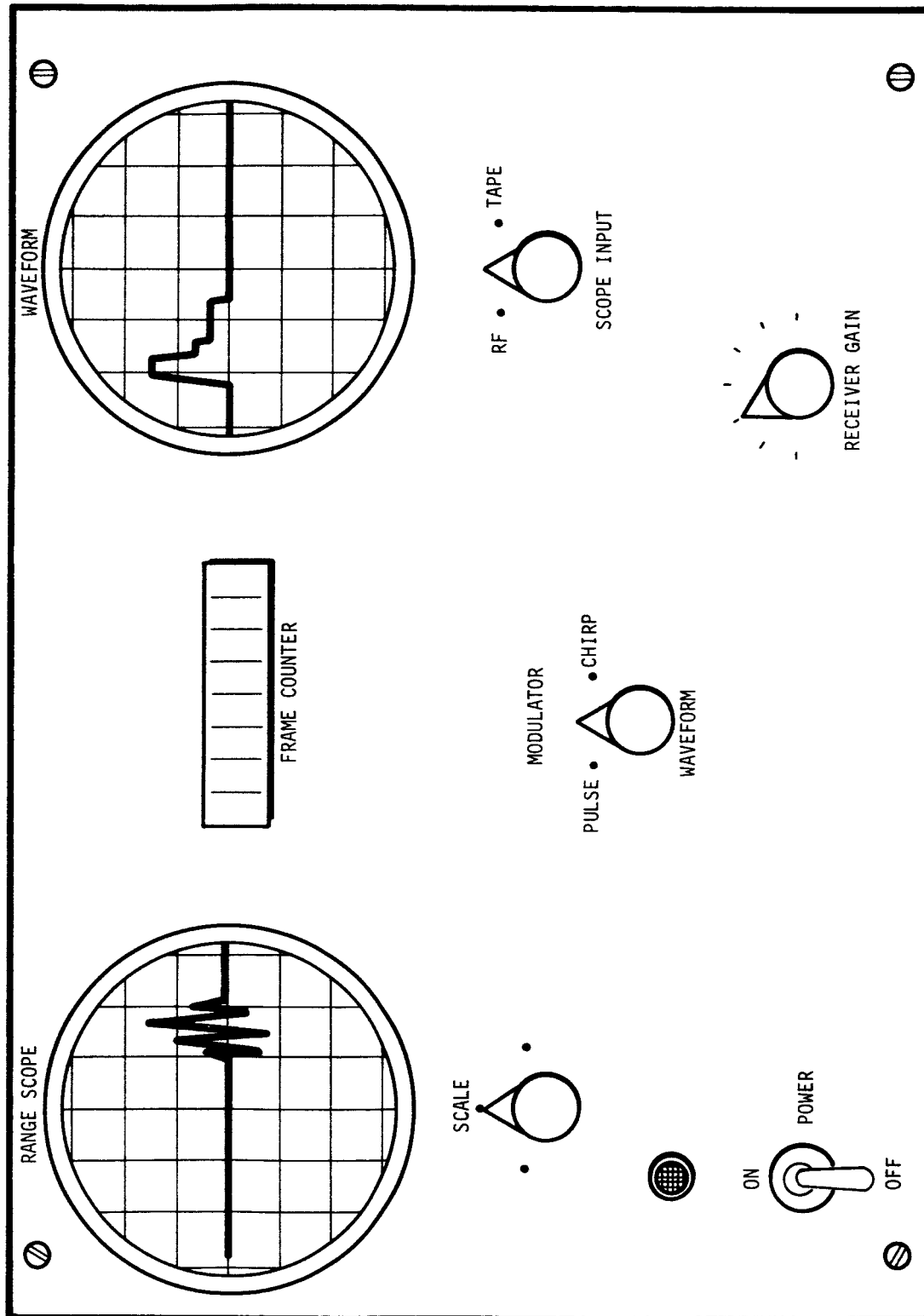


Figure 11. Radio Reflectometer Control Panel

analyzed and compared electronically so that differences in the characteristics of the two waves are displayed as a single pulse of quite different waveform and new geological information content. Also the two echo waveforms may be compared with that of the longer wave radio reflection pulse. It is expected that questions may be answered which pertain more strongly to lunar dust. Its roughness, thickness and electrical properties will be emphasized through the use of the shorter wavelengths.

Knowledge of the surface permits better understanding of the subsurface. The lunar dust is formed in part by radiation destruction of the original material, and variations in the original rock types will in turn produce dust with associated variations. There has been little opportunity for extensive investigation of these metamorphic processes and the radar studies represent new data and unexploited methods and techniques. It is probable that the number of different surface effects is few, and that the echo waveforms will serve to establish a lunar dust classification suitable for evaluation of different parts of the Moon, or different types of lunar craters.

Instrumentation for the radar altimetry and surface state measurements is necessarily similar to that of the radio reflectance equipment. Additional weight must be added for the antenna structure; however, this is to be mounted outside the normal storage compartments. The additional volume of the antenna can be small if an umbrella design is developed to permit antenna structure erection after the spacecraft attains a lunar orbit.

Because of the similarity of equipment, Figures 10 and 11 illustrate the radar altimetry system. The data is to be recorded on magnetic tape for transmission by radio to Earth.

Utilizing the same portion of the electromagnetic spectrum, the coherent imagery radar is designed to provide a small map of a large section of lunar surface in the vicinity of the suborbiter surface point.

From the height of the orbiter the horizon distance is 521 km; however, no attempt has been suggested to cover this large area. Figure 12 presents the proposed imaging geometry. Using the radar beam to scan within 26 degrees of local vertical the radar will cover a swath width of 40 km. This will be done on only one side but will include an area approximating the cartographic camera coverage. The pulse length of 53 nsec provides a resolution of about 16 m. The image produced is to be photographed on 8 mm film for development on Earth.

Ultraviolet Absorption Luminescence

Strong atmospheric absorption has deterred any extensive use of ultraviolet in aerial photography; however, good results are to be expected on the Moon. Calcareous terrain materials are revealed in great contrast by UV sensing⁵. The majority of the atomic absorption lines fall in the UV band, and radiation from lunar rocks may be excited within these bands by atomic radiation from space and from the Sun. An identification of the lunar surface materials may be possible with ultraviolet observations just as with infrared. Similar methods may be used to record the ultraviolet intensities. Schmidt optics have been developed by the Perkin Elmer Corporation for use in both imaging cameras and grating spectrographs¹⁷.

The use of ultraviolet in the study of minerals is not new or unusual; however, only active methods have been employed. From orbiter altitudes the lunar surface cannot be illuminated with ultraviolet light with significant intensity, and only the radiation of natural origin is to be sensed. In the lunar daylight the Sun is expected to produce ample UV illumination but in the dark phase of each orbit the sensitivity of the UV detectors is questionable.

A grating spectrometer is recommended for the orbiter flight. The UV spectrometer shown in schematic cross section in Figure 13 is a Perkin Elmer model which was carried by a rocket during an atmospheric air glow study¹⁷. With the grating shown (2160 lines/mm), a spectrum

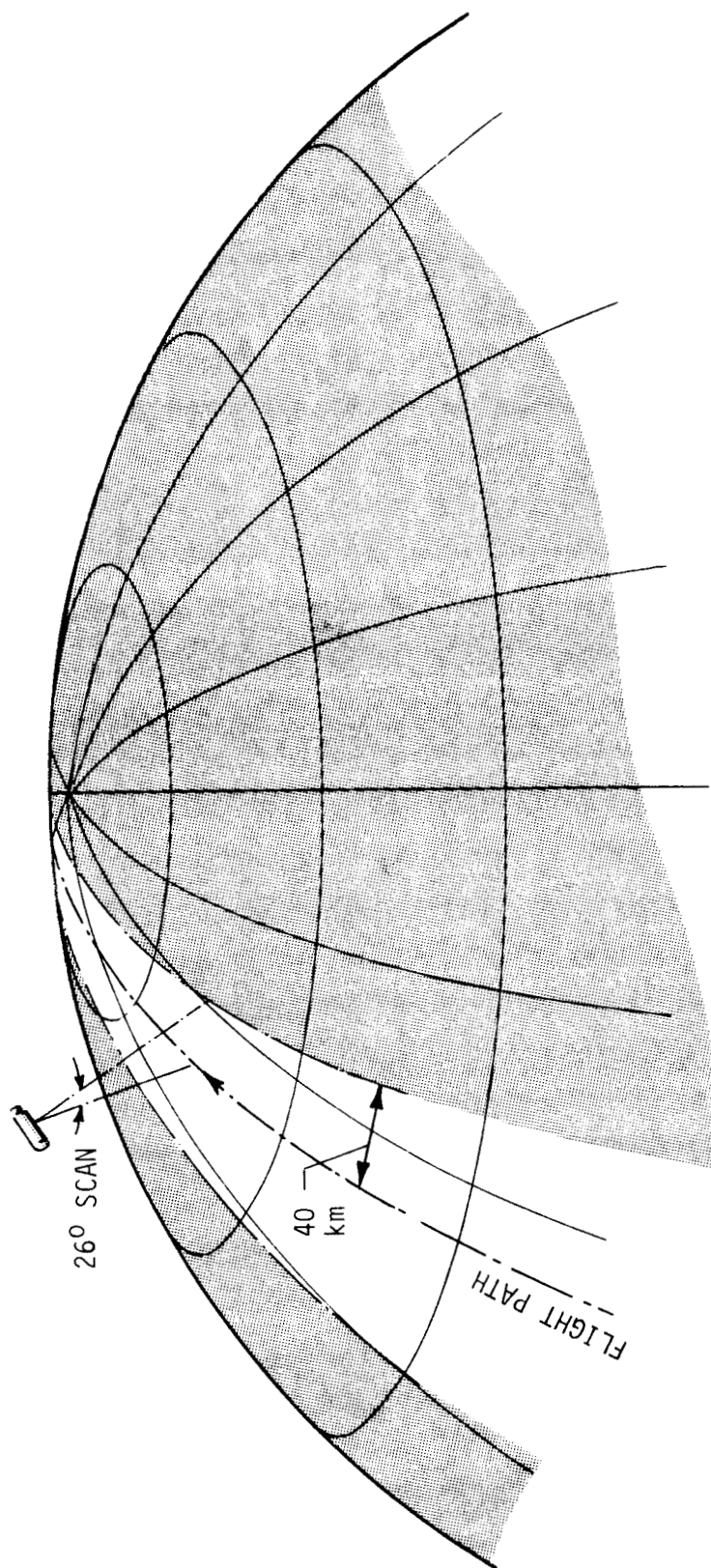


Figure 12. Geometry for Radar Imaging of the Lunar Surface

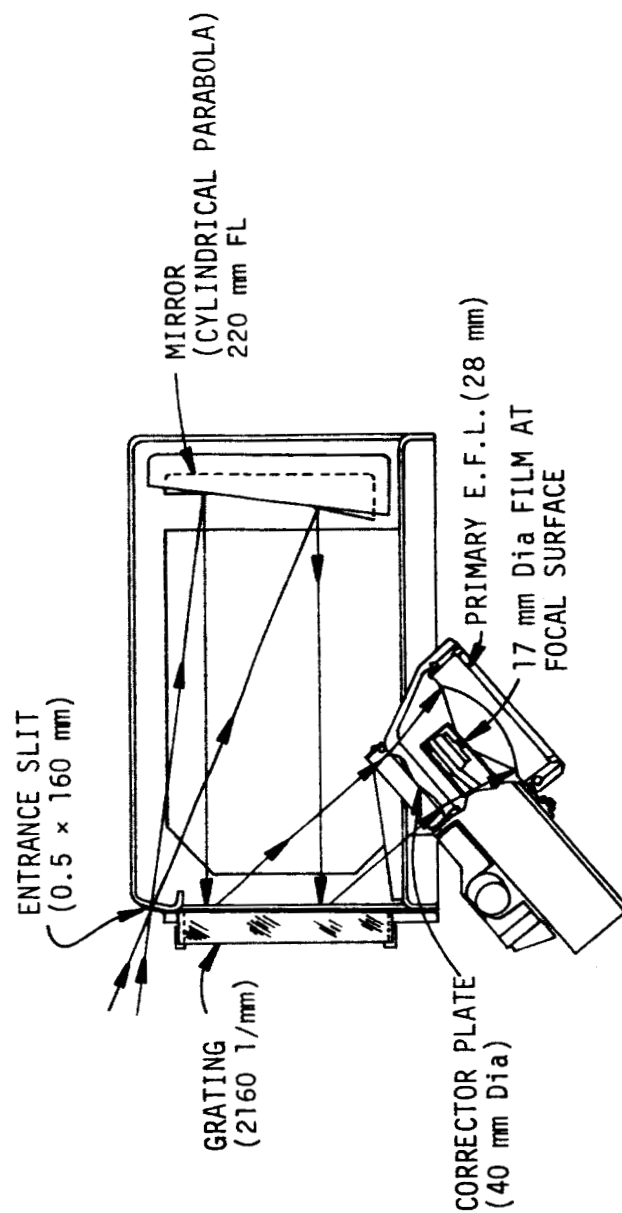


Figure 13. The Airglow Spectrograph. The off-axis cylindrical parabola collimator and the f/0.7 Schmidt camera make a very fast system.

was photographed covering the range from 2500 to 3900 Å. Slightly shorter wavelengths have been suggested for the study of lunar surface materials. Diffraction gratings with rulings coarser than those cited above have been used below 2500 Å.

The Schmidt optics used with this model provides a small angle of resolution (1/4 degree). This spectrometer should be mounted with the imaging experiments so that the same tracking mechanism may be used for aiming the UV radiometer. A UV spectrum may be photographed in this way for each cartographic mapping picture. The spectrometer slit should be aligned across the flight path where the field of view of the optical system permits exposure to a strip of lunar surface 0.71 km long for 10.2 sec. The resulting spectrum is recorded on a circular film area 1.7 cm in diameter. For orbiter use, a means must be provided for film drive and for registration of the desired frame number on each spectrum. A remote control for the slit adjustment and an internal photoelectric cell for UV will permit astronaut monitoring and adjustment of the photography within the UV spectrometer. Figure 14 is a suggested control panel for use by the astronauts in monitoring and controlling the UV spectrograph operation.

Alpha Particle Emission

These atomic particles are emitted by radium and a number of other radioactive elements. The particle energies are generally greater for chemical elements with a longer half life and the energies also exhibit discrete levels which are characteristic of the chemical element. The penetration of the particle is only a few inches of air but in space and in a vacuum the range is much greater. The detection of these particles above the lunar surface will indicate that radioactive disintegration is present on the lunar surface¹⁸. The alpha particles may also be produced by transmutation processes on the Moon due to cosmic rays. Additional alpha activity is expected to correlate with solar activity. This phase of the study will be emphasized only if unusually high solar activity coincides

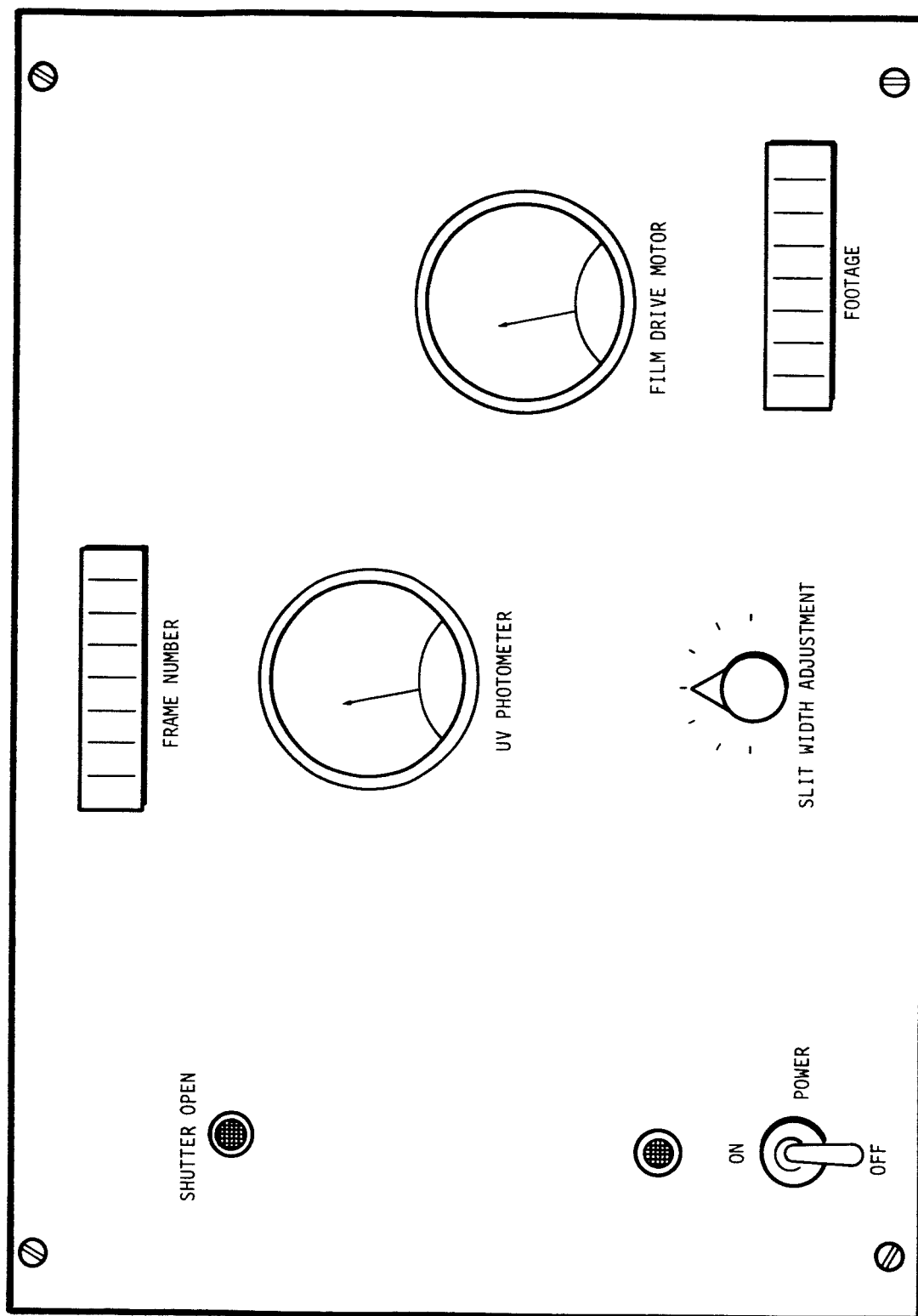


Figure 14. UV Spectrograph Monitor and Control Panel

with the flight schedule. The alpha activity in this case should correlate with ultraviolet and optical spectra observations. The flux of alpha particles is not expected to be high at any point on the lunar surface and detectable quantities of radiation at orbiter height and speed must be associated with large areas of the lunar surface. A high resolution detector accordingly is not recommended if sensitivity is sacrificed. Directivity in alpha particle detectors is attained with collimator tubes and radiation shielding.

The apparatus shown in Figure 15 is designed for detection of alpha particles and registration of the flux at 10 different energy levels. A solid state detector is indicated with an anticoincidence circuit to remove background count due to higher energy particles. The housing for the detectors serve as shielding for all high energy particles except those entering the collimating tube. In operation this tube is directed toward the lunar surface, and the cartographic image tracking mechanism may be used to aim the alpha detector. In this way the alpha particles will be counted for 10 seconds for each lunar surface area sampled and photographed. The circuits following the anticoincidence unit sort the particles according to energy. The particle count at each of 10 energy levels is recorded as a digital word on magnetic tape.

For monitoring this equipment it is planned to have the pulse analyzer unit within view of the astronaut. This instrument has indicator lights showing the counting process and the total particle counts at the time the data is recorded on tape. Calibration of the instrument is obtained by means of a standard sample of ionium or any of the radioactive elements having a long half life. Remote control means are provided for an occasional positioning of the standard sample in front of the detector window. The astronauts may then observe a corresponding counting rate.

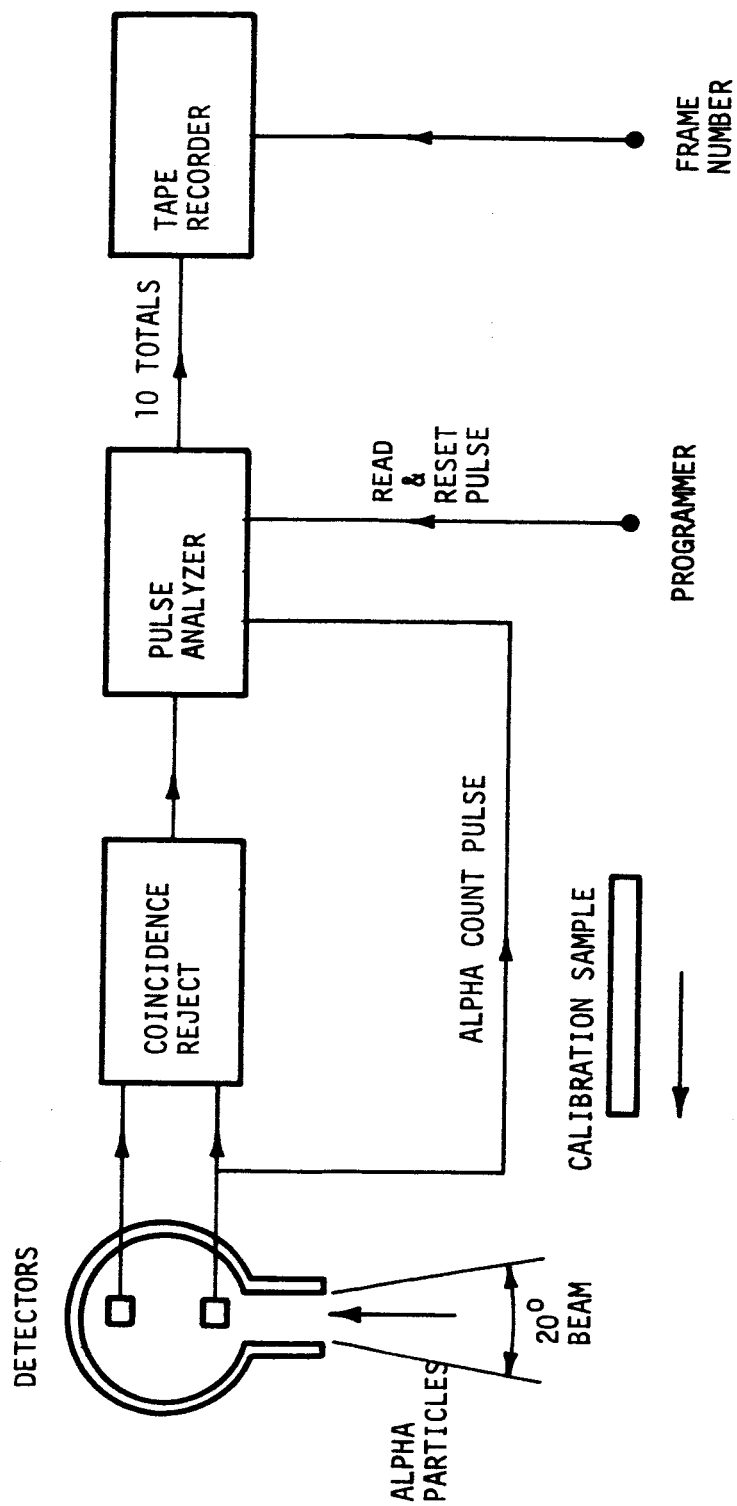


Figure 15. Alpha Particle Detector

Micrometeorite Detection and Collection

A part of the study of the lunar surface includes the study of meteorites. They have contributed to the abrasive processes appearing as erosion of lunar features, and by accretion they contribute to the aggregate of lunar surface materials.

A better understanding of lunar history may result from an expanded knowledge of meteorites. Although the orbiter is not expected to encounter any dangerous meteorites, a number of small impacts are expected. For future exploration, an evaluation of the hazard of meteor impacts on the lunar surface is of immediate significance.

The frequency distribution of meteorites of different sizes and energies will be tabulated by the lunar orbiter apparatus, and samples will be collected for more specific and detailed study. This should permit an analysis of meteorite chemical content, physical characteristics, and crystal structure and also permit measurement of radioactivity and isotope ratios and permit any other observation of the results of their long exposure to cosmic or solar radiation. The equipment on the orbiter consists of separate collection and detection apparatus.

Indicated schematically in Figure 16a is a suggested meteorite experiment for orbiter use¹⁸. Collimating tubes with square cross section are shown which permit meteorites from two opposite directions to reach the collection plates. These plates are metal with soft coatings in which the meteorites become embedded. Means are provided for protection of these collection surfaces until a stable orbit is attained. The tubes are positioned outside the spacecraft to have an unobstructed view of the sky with a minimum chance of contamination from rocket exhaust. Recovery of the plates and their protective packaging is planned as an extravehicular activity of the astronaut, and recovery of the trapped meteorites is scheduled as an Earth operation following the flight termination.

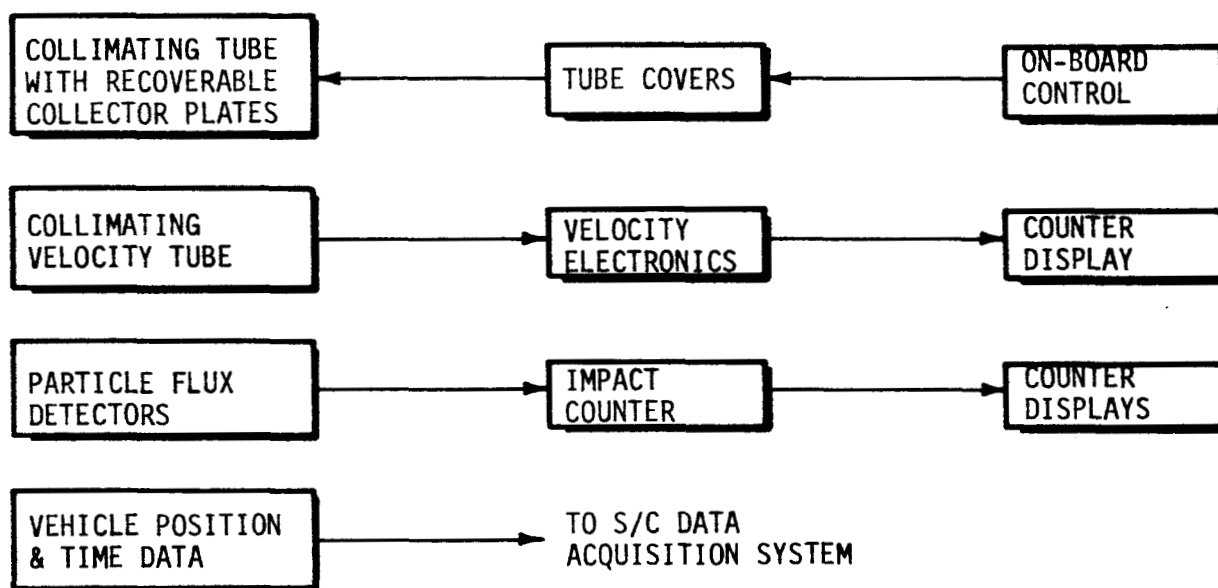
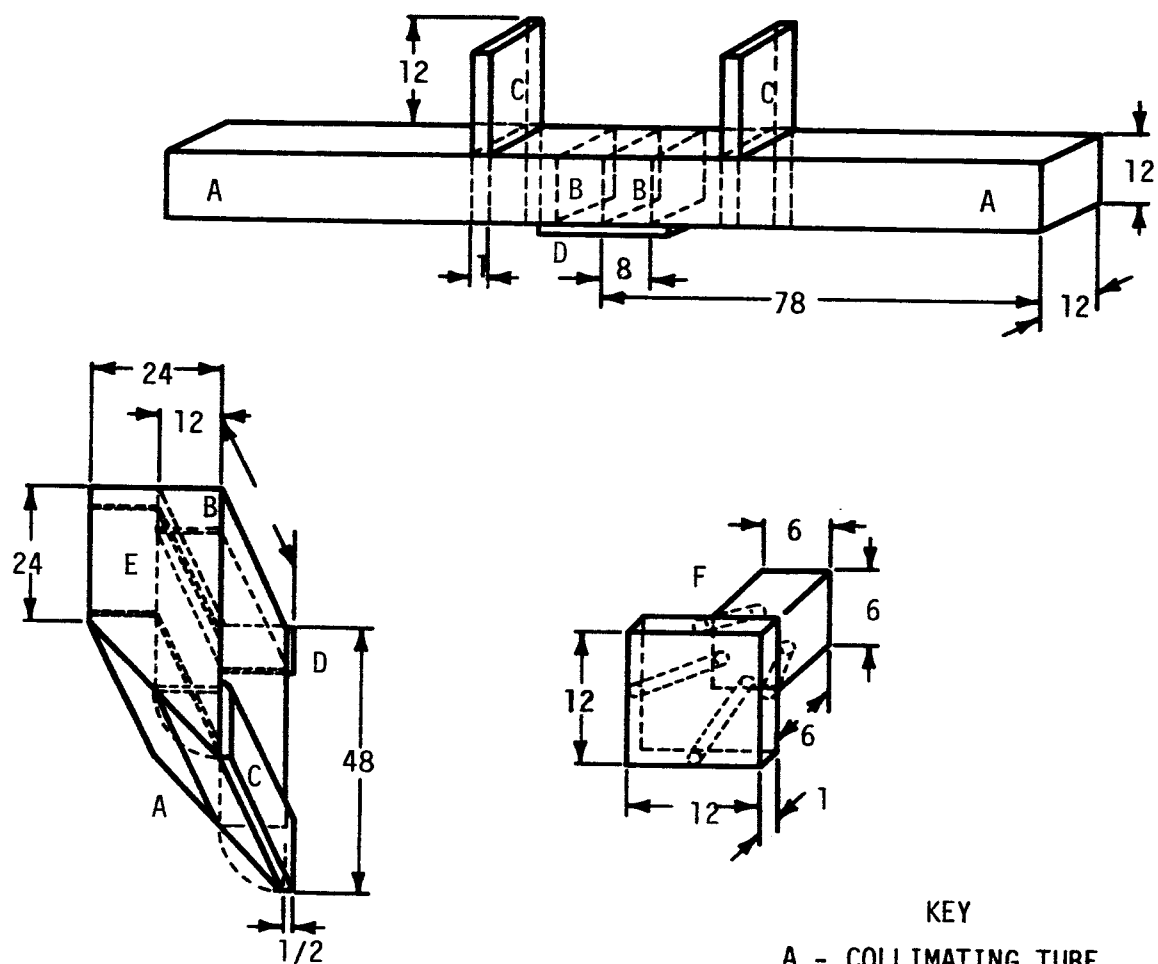


Figure 16a. Micrometeorite Collection and Detection (From Reference 18)

Indicated in Figure 16b in block diagram form is one recording channel of the meteorite impact momentum detectors. Six of these metal squares are mounted outside the spacecraft where they have an unobstructed view in six directions. They receive impacts from above and below, right and left, and from front and rear. The metal panels act as sounding boards to transmit the sound from the meteorite impact point to a sensitive vibration pickup. The plates are shock mounted to isolate them from normal vibration originating within the spacecraft. The pickups generate electrical impulses proportional to the momentum of the meteorites. These pulses are sorted according to size in the impulse analyzer and the number of counts in each of 10 sizes is totaled at completion of the last orbit. Since the six collimating tubes open toward different parts of the sky at different times, meteorite impacts cannot be totaled for each plate. Star tracker or inertial guidance data must be used to sense the orientation of the meteorite detectors. The impacts are tallied accordingly. Figure 17 shows a digital matrix suitable for photographic recording at the completion of the mission.

X-Ray Fluorescence

The Sun is the most energetic source of x-rays for measurements from the lunar orbiter¹⁸. This radiation is expected to initiate secondary or fluorescent x-rays from the lunar surface materials. The K and L emission bands are expected to be excited in the lunar surface materials only during solar flare activity, but with normal Sun activity only the longer wave x-radiation is excited and equipment designed for sensitivity in the spectrum about 7 Å is recommended. Ionization counter tubes have sufficient sensitivity and the use of thin metal films as x-ray filters permit selective intensity measurements to be obtained. This spectral data is expected to compliment the IR and UV spectral data in the analysis of lunar surface material. The x-ray method is somewhat untested as the Earth atmosphere absorbs the Sun's x-rays and prevents fluorescence of the Earth materials. Normally the x-rays are considered as highly



KEY

- A - COLLIMATING TUBE
- B - FOAM COLLECTING PLATE
- C - TUBE COVERS
- D - COLLECTOR ACCESS
- E - VELOCITY TUBE
- F - PARTICLE FLUX

ALL DIMENSIONS IN INCHES

Figure 16b. Micrometeorite Collection and Detection Dimensions
(From Reference 18)

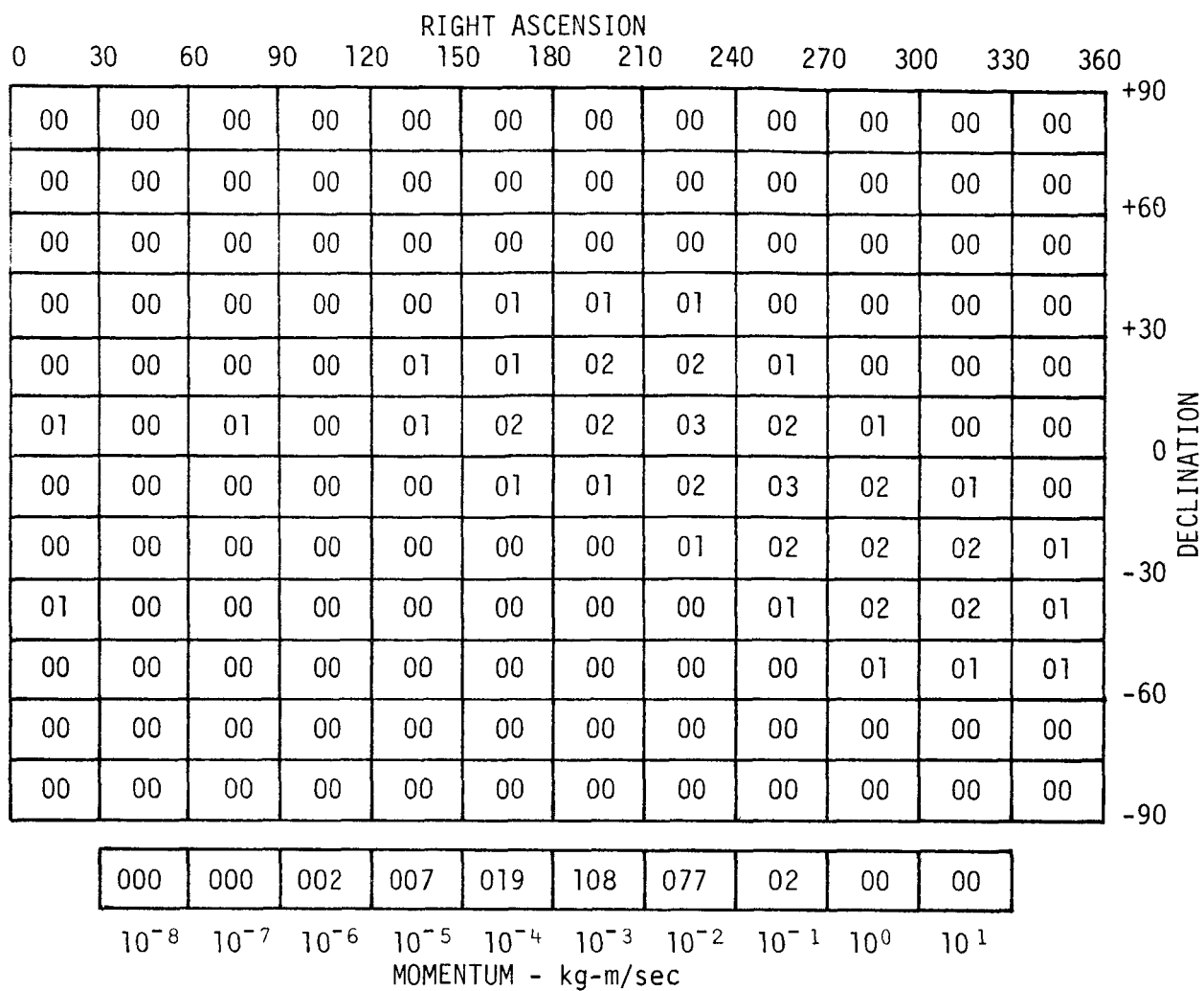


Figure 17. Micrometeorite Impacts

penetrating; however, the fluorescent x-rays are characteristic of only a few millimeters of lunar surface material. Since the fluorescent radiation is dependent upon the x-rays from the Sun, it is necessary to monitor the Sun at the same time that lunar intensities are measured.

The schematic illustration of Figure 18 illustrates the important functions in the x-ray system. The gas-filled counter tubes are shown enclosed in shielding to protect them from extraneous radiation within the spacecraft. The detector assembly is mounted outside the orbiter where the collimator tube may be directed toward the Moon. The anti-coincidence circuit serves to reject impulses due to radiation of sufficient strength to penetrate both counter units and the shielding between them. A selection of x-ray filters is sequentially placed before the window to permit intensity observations at several x-ray wavelengths. The programmer serves to control the filter positioning and to register the intensity after several seconds exposure with each filter.

Gamma Ray Mapping

The gamma rays are the most penetrating of the three types of atomic radiation and accordingly may reveal the presence of radioactive material beneath the lunar dust at depths of several centimeters. The rays may also occur as the result of cosmic ray bombardment. In each case the energy of the gamma ray is an identifying characteristic of the material. If radioactive elements are identified on the Moon, this will be considered as a clue to lunar history and structure. The elements, uranium, thorium, and potassium, are expected to be present only if there has been mineral differentiation during a part of the Moon's formative period. Similar concentrations may also be expected for other minerals which have value but are less easily detected.

In geophysical prospecting of the Earth, the gamma detector has proven successful in airborne applications. The natural radiation from the soil may be detected from low flying aircraft and the absence of

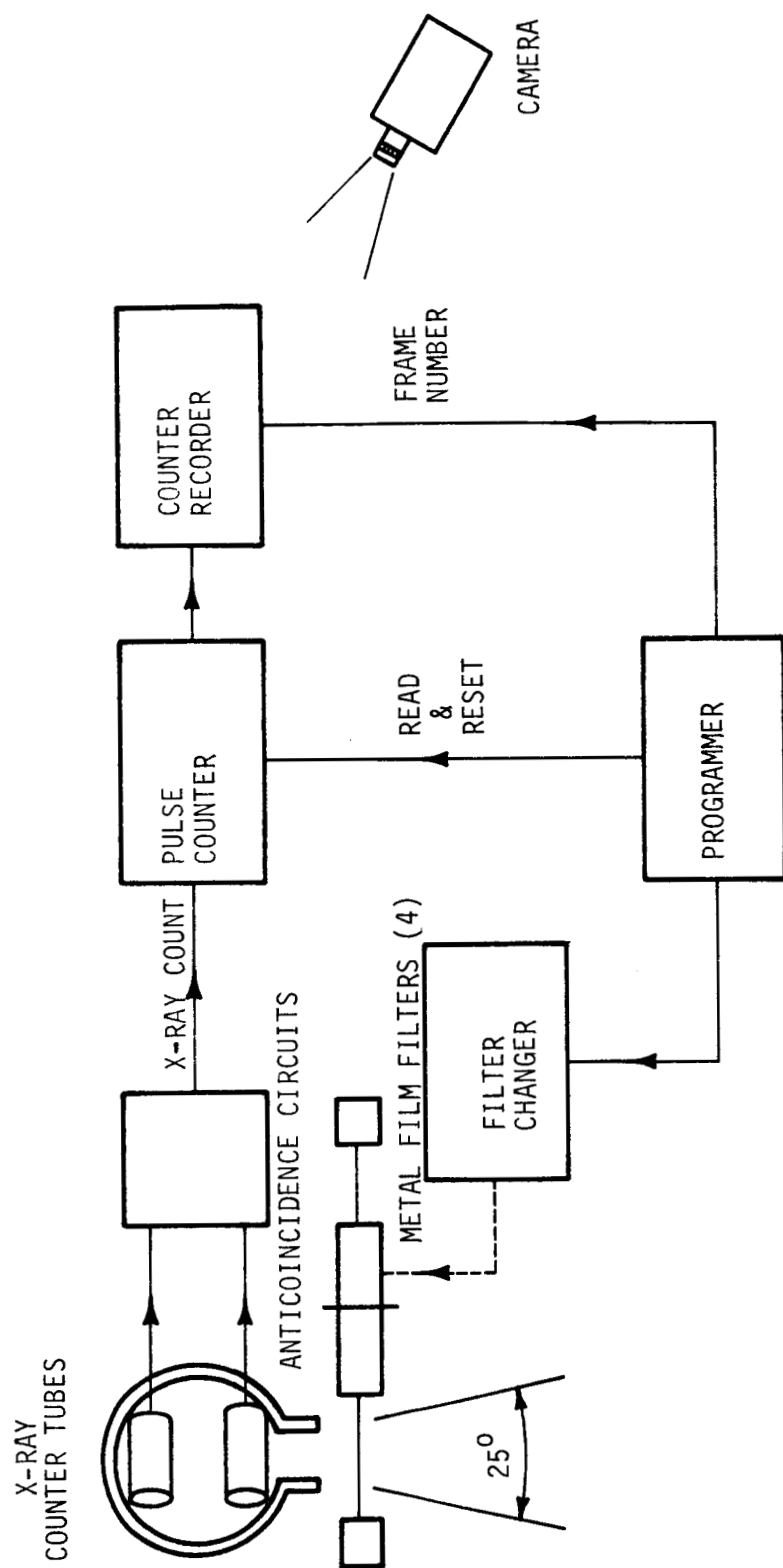


Figure 18. X-Ray Fluorescence Recorder

radiation over lakes serves as the calibration check. The absence of a lunar atmosphere is expected to permit the operation of the instrument at lunar orbiter altitudes. Since the directional sensitivity of the gamma detector is not easily confined to a narrow beam, a high resolution gamma radiation map from orbiter altitudes is not planned.

The Compton telescope incorporates two scintillation counters in a coincidence circuit. Crystals of CsI are usually large to improve the chances of scintillation production by the highly penetrating rays. The telescope should be mounted on the image tracking mechanism of the cartographic camera to insure that ample exposure time is provided for the surface area sampled. The schematic illustration of the gamma ray equipment is shown in Figure 19. The 10-channel analyzer sorts the double scintillation flashes according to intensity and stores the total count during the 10.2-second intervals between successive frame numbers. Since conventional models of this instrument have panel lights to indicate its counting state, the analyzer is to be mounted within sight of the astronauts for use in monitoring the gamma ray recording system.

Remote Geochemical Sensing

Specific chemicals are selected as possible lunar atmosphere constituents in this test. Because of the reduced pressure there is little resemblance between the lunar atmosphere and that of the Earth. The usual gas laws and fluid properties are not expected to be observed in the lunar atmosphere. Instead, the effects of sputtering of the lunar surface are expected to produce a number of monatomic molecules which may be detected even though the particles are highly transitional. An additional seepage of chemicals is expected from inactive volcanic sources or from the normal destructive processes on the lunar surface from micrometeorite bombardment. Iodine, sulphur and mercury have been detected in the Earth's atmosphere as products of similar activity. Although these particles do not migrate rapidly to high altitudes on the Earth, it is probable that they are less restricted on the Moon. The concentration of these chemicals is

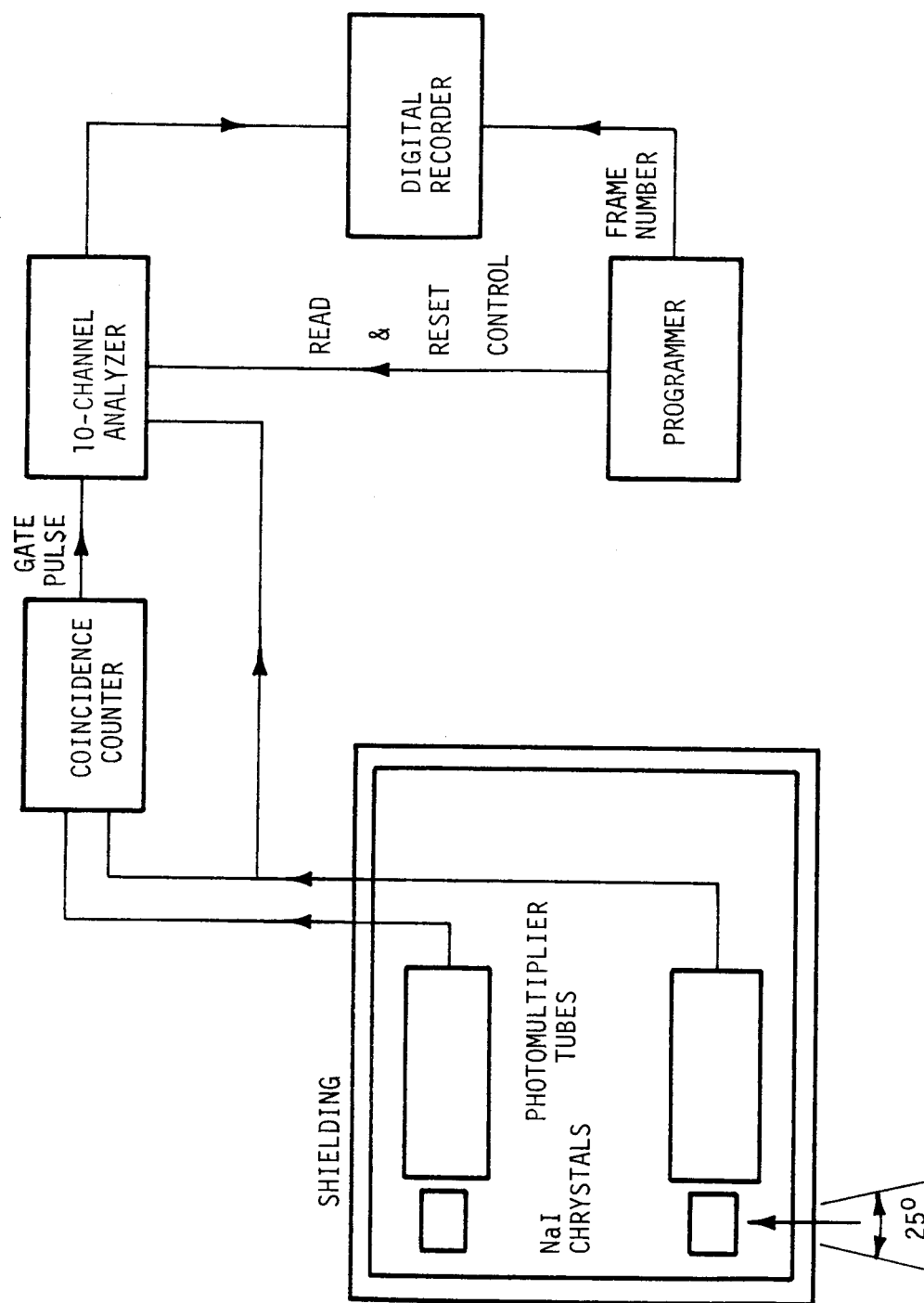


Figure 19. Gamma Ray Recorder

extremely low, and no evidence of their existence above the lunar surface has been uncovered. A more detailed test program is actually needed at a fixed site on the lunar surface in order to determine which specific vapors are present and which forms of apparatus can best be used. For the orbiter program, the most feasible test consists of an automated form of the vapor detector with output recordings for one or two chemical elements normally associated with igneous rock or volcanic processes.

Similar to the ultraviolet spectrometer this apparatus senses the absorption of particular spectral lines by lunar atmospheric vapors. The instrument is calibrated against sunlight spectra existing at the time. A sample of the desired atmospheric chemical is used as a filter in a differential optical system to provide great sensitivity for the specific spectral lines of interest. Sunlight from the lunar surface is sensed; however, the absorption to be detected occurs along the light path between the surface and the orbiter. Only a few million atoms are needed to produce an indication. In schematic form the apparatus is illustrated in Figure 20, taken from Reference 18.

Star Tracking

The star tracker provides celestial navigation data for the lunar orbit flight programming attitude control and lunar surface experiment coordination³. To provide accurate control of the lunar photographic survey and to correct for photographic distortion in the mapping process, the orbiter selenographic position must be determined frequently.

The inertial horizon used as a reference for aiming the cartographic camera or leveling the spacecraft must be checked against an independent standard such as the star pattern to correct for gyro drift. Additionally the perturbations in the spacecraft orbit may be determined from celestial observations. The precise determination of the spacecraft trajectory permits the radar observations to be used for delineating the true figure of the Moon. The combined data on the shape of the orbit and

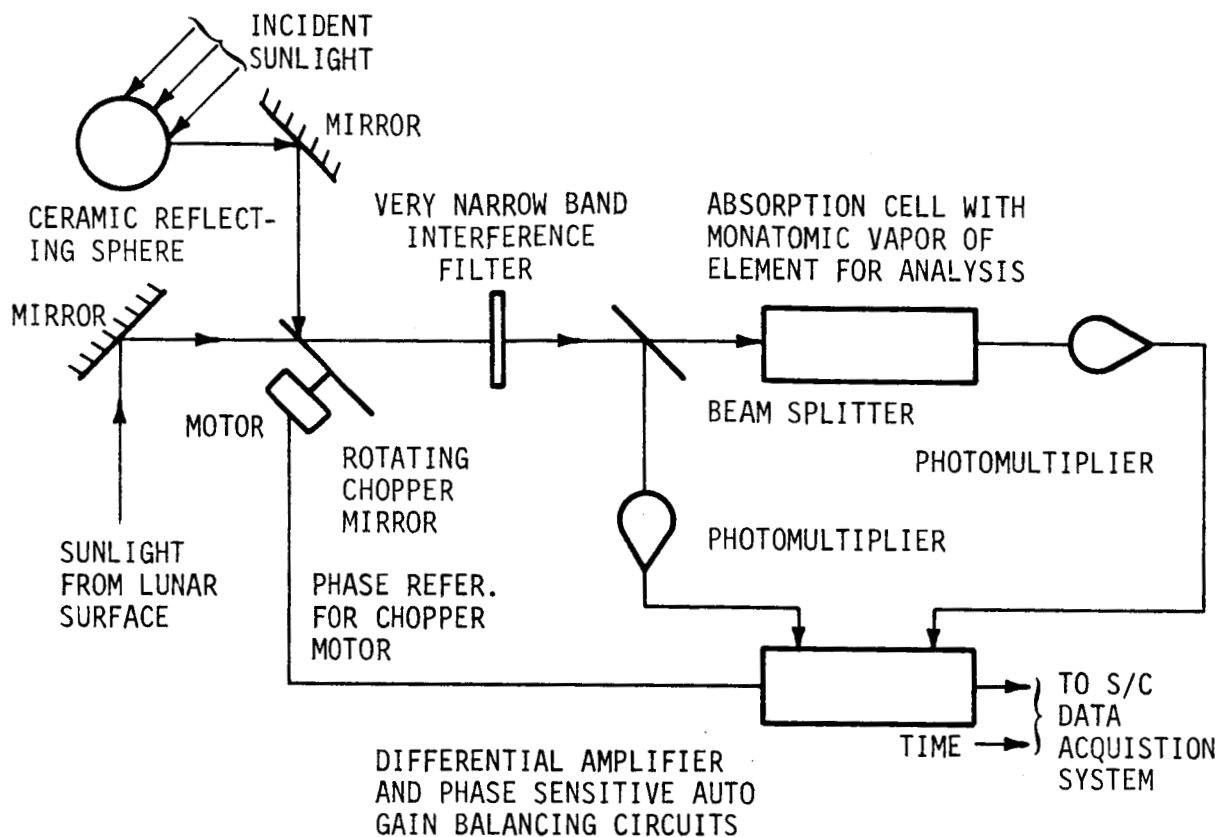


Figure 20a. Remote Geochemical Sensor (From Reference 18)

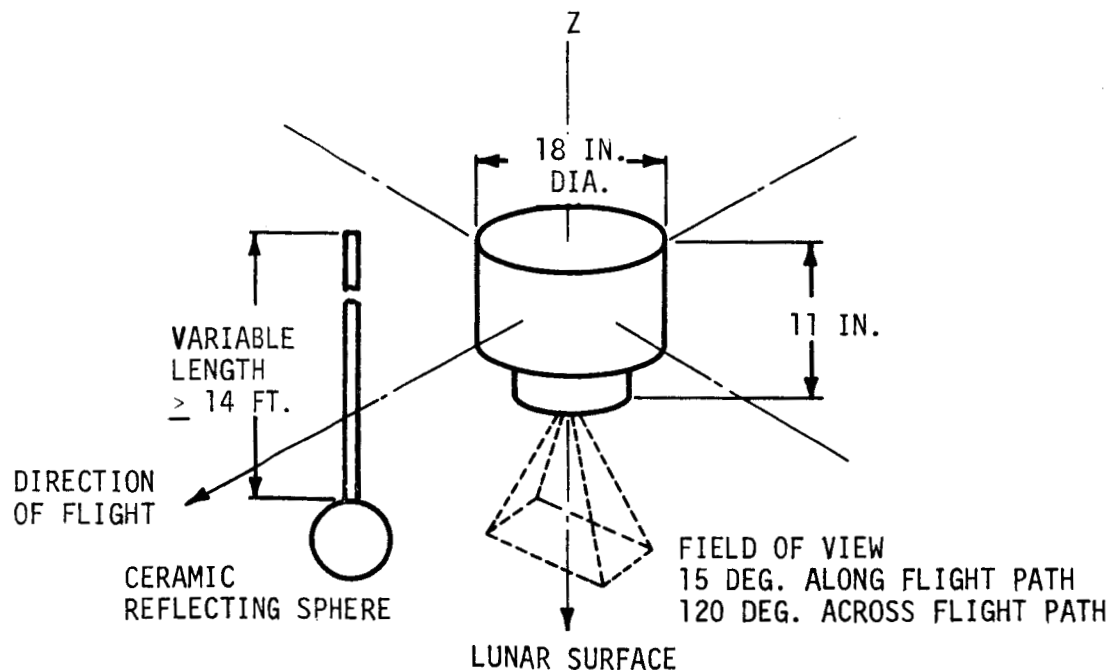


Figure 20b. Remote Geochemical Sensor Dimensions (From Reference 18)

the shape of the Moon permit computation of the lunar gravitational field. Spacecraft attitude data is additionally necessary for computation of the micrometeorite collimator orientations. Accurate position data on the orbiter is of further value for flight dynamics computations associated with leaving the lunar orbit and entering the home trajectory. Data from the star tracker is needed by the Experiment Programmer unit since this instrument contains the schedule for camera operation. The schedule provides actuator signals for the cameras which must be synchronized with the orbiter latitude. If an error is made in obtaining a circumpolar orbit, then both latitude and longitude data are needed for camera coordination. For photographic purposes the stability of the spacecraft in pitch and roll is normally adequate; however, star tracker data will provide a suitable reference as an alternate standard or method in the event of inertial guidance failure. Additional study is recommended to establish the feasibility of a guidance design permitting the astronaut's choice between stabilization control by inertial and by celestial sensing.

The star tracker is a cluster of four telescopes or theodolites. With servo control these are directed toward fixed stars. As each star becomes lost from view the corresponding theodolite is directed toward a new star. Each theodolite angle is sensed with respect to spacecraft axes with a precision of 7 arc seconds¹⁹. The tracker assembly is mounted on top of the orbiter to provide an unobstructed view of the sky for all the theodolites. The information on theodolite position angles may be processed by digital computer to determine the attitude of the spacecraft and the necessary guidance control for corrective action. Additional computation provides the astronauts with a continuous readout of selenographic latitude and longitude of the lunar surface suborbiter point. This information is also recorded with a corresponding frame number for coordination with the lunar surface observations. In coded form the information is accepted by the Experiment Programmer for use in camera control. The time data needed for orbiter position computations

may be determined from the Earth by radio link or may be generated by a precision oscillator within the spacecraft. In Figure 21 the star tracker is presented in conceptual form. Also indicated are the associated monitor and control panel for the star tracker.

INSTRUMENT SUMMARY

In Tables 5 and 6 a listing of the experiments is presented with characteristics of the apparatus which influence their integration into Flight 511. These are weight, power, space, and data volume. The specific values presented in the tables have been taken from References 14 and 18 in most cases, although a few of these values have been modified. Totals presented are within the limits and specifications presented in Vehicle Configuration for the specific spacecraft assembly, Apollo capability, and lunar orbit objective. Specific details of installation do not appear critical; however, special attention to data recovery is necessary because of the limited radio and telemetry channel capacity, and the low weight limitation of the return payload.

DATA PROCESSING

Storage

Some of the data must be stored for the full duration of the mission. Other forms of data must be stored only until radio or telemetry channels are open. Data stored on film is invariably an image and never in a form requiring playback such as moving pictures or sound track. The film data is a series of discrete frames which are to be studied or read individually. This makes up the largest portion of the data, and all such film must be returned to Earth within the load limit of 250 lb. Where measurements accrue in the form of several readings per frame number, it is convenient to use photographic pictures of the instrument output scale or counter. A large number of outputs may be included in

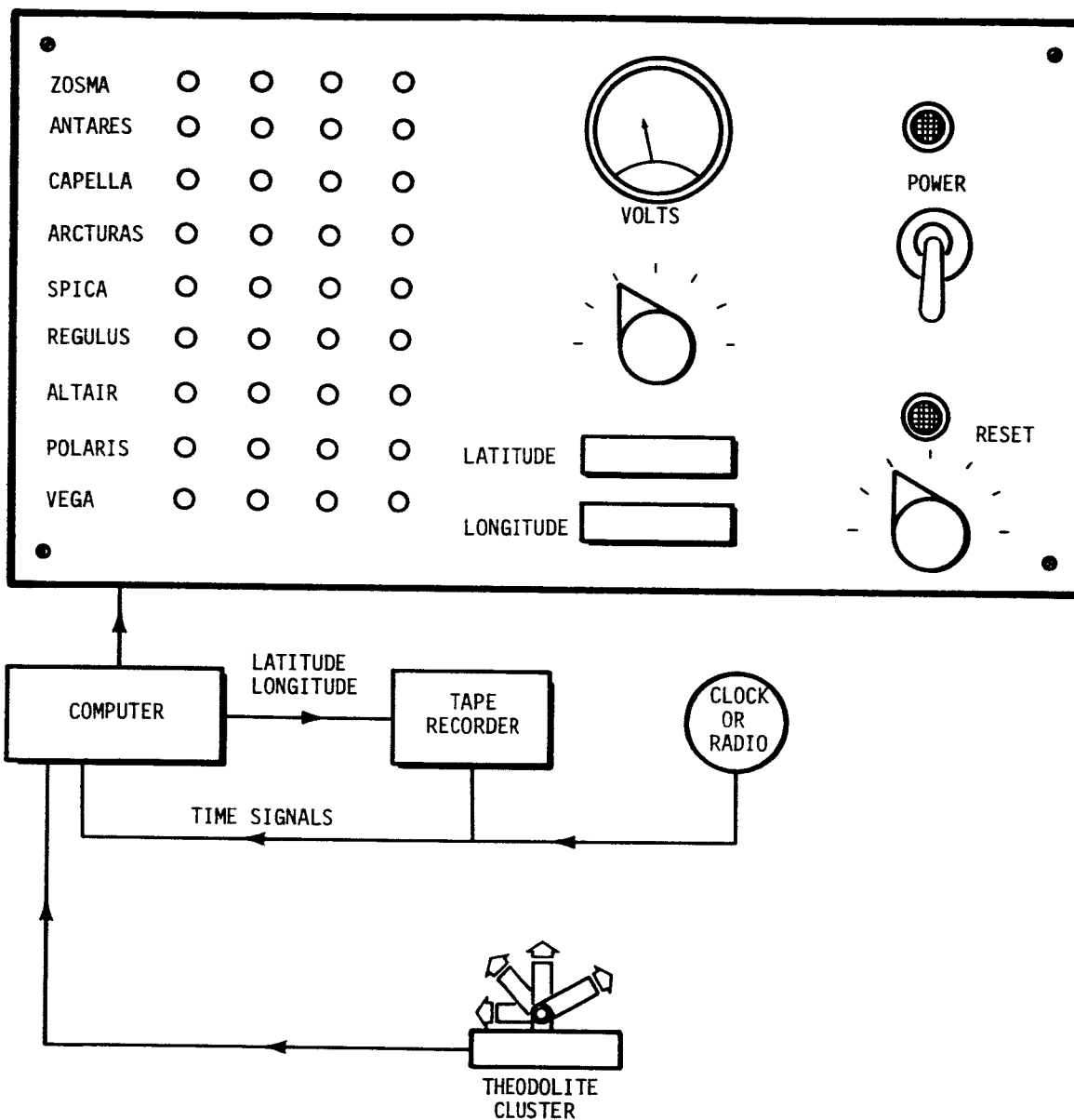


Figure 21. Star Tracker Theodolites and Monitor and Control Panel

TABLE 5
PAYLOAD SUMMARY

Experiment		Weight (lb)	Volume (ft ³)		Power (W)
			Unpress.	Press.	
Programmer		20.0		1.0	15.0
Photography	(Optics)	186.0	4.0	1.0	25.0
	(Film)	180.0	15.0	0.0	0.0
Infrared Surveying	(Imaging)	11.3	15.8	0.3	4.0
	(Spectral)	23.0	1.1	0.3	10.0
Passive Microwave	(Imaging)	100.0	26.0	0.3	100.0
	(Spectral)	100.0	36.0	0.3	200.0
Radio Reflectance		43.0	19.0	0.3	42.0
Radar Altimetry and Imagery		447.0	50.2	0.3	1620.0
UV	Absorption (Optics)	10.0	0.4	0.3	1.0
	Luminescence (Film)	8.0	0.1	0.3	
Alpha Emission		12.4	0.4	0.3	6.2
Micrometeorites		760.0	33.4	0.3	0.0
X-Ray Fluorescence		27.5	4.5	0.3	42.2
Gamma Ray Mapping		41.5	3.7	0.1	14.2
Remote Geochemical		50.0	2.1	0.1	15.0
Star Tracking		19.8	0.9	0.3	16.0
Data Film		18.0		1.0	
Oscillator		15.0		1.0	15.0
Second Tape Recorder		26.0		1.0	33.0
		1414.9	212.6	8.8	2158.6
					for 192 h (415 kWh)

TABLE 6

DATA SUMMARY

	Optical Resolution (deg)	Scans per frame*		Maximum Frequency (cps)	"On" Time per Frame (sec)	Image Motion Compensation	Recorder Film - F Tape - T
		sec	frame*				
High Resolution Photos	7×10^{-4}		1		0.02	Yes	F 110.8 lb 69.2 lb
Spectral Photos	35×10^{-4}						
IR Image	0.5	0.5	20	250	10	No	F scope picture
IR Spectra	5.0	0.1	1	250	10	Yes	T analog
Microwave Image Spectra	3.3	0.3	3	10	9	No	F scope picture
	3.3	0.3	1	10	3	Yes	F digital**
Radio Reflectance	--	100	1	3×10^8	0.1	No	F scope picture
Radar Reflectance Imaging Altimetry	2	100	1	10^{10}	0.1	No	F scope picture
	2	20	10	10^{10}	0.5	Yes	F scope picture
	--	--	1	10^{10}	0.1	No	F counter picture
UV Spectra	1/4	0.1	1	250	10	Yes	F 8 lb film
Alpha Detector	20	--	1	10^3	10	Yes	T digital†
Micrometeorites	8.75	--	--	--	all	No	F only one photograph
X-Ray Fluorescence	25	--	1	1 k H ₂ impulse	all	Yes	F 4 digital numbers per frame

TABLE 6 (Continued)

Optical Resolution (deg)	Scans per frame*		Maximum Frequency (cps)	"On" Time per Frame (sec)	Image Motion Compensation	Recorder	
	sec	frame				Film - F	Tape - T
Gamma Ray Mapping	25	--	1	1 kHz pulse	all	Yes	T Digital [†]
Remote Geochemistry	25	--	5	100	all	Yes	T Digital 5 numbers/frame
Star Tracker	--	--	--	--	all	No	T Digital ^{††}
Frame Number	--	--	--	--	--	No	T 10 bit word once per frame

* A frame is a field of view $11.3^\circ \times 22.6^\circ$.

** Six channels with four readings each.

† 8 bits per word; 10 words per frame.

†† 15 bit words for four azimuth and four elevations and time;
9 numbers per frame.

one photograph on 8 mm film. There are 682 frames per orbit, and normally 80 frames per foot of 8 mm film. During the entire mission the film length is 855 ft and weighs about 2 lb.

Magnetic tape recording is used for handling high data rates due to wide dynamic range in the measurements and to fine detail in the lunar observations. Since large quantities of tape are required, data storage time is planned for only one orbit.

Data Transmission

It is planned to transmit all tape recordings by telemetry to Earth during the appropriate phase of each orbit. This requires two recorders to permit continuous data recording during the data storage, data transmission, and tape rewind periods. It is planned to record during even-numbered orbits on one machine and during odd-numbered orbits on the other. Time compression of 4:1 is attained through fast playback capability of the tape recorders during radio transmission. By the use of subcarriers, three analog data channels may be transmitted simultaneously to Earth. Digital data also may be transmitted on an adjacent carrier. It is possible to connect a sensor directly to a radio transmitter; however, this is not planned. A direct link to Earth lacks time compression capability and is incapable of continuous operation for a complete orbit. The programmer has the capability for control of data transmission. By sensing either the frame numbers or the orbit counting recorder, the programmer may transfer the data input to the other recorder and tape can be rewound. Also, radio contact with Earth may be confirmed, and taped data may be sent. Appropriate indicator lights permit the astronauts to monitor the automatic data transmission and over-ride controls permit manual conduct of the operational sequence. It is important to establish that good data reception on the Earth has been attained before spacecraft tapes are erased.

A summary of the data processing is presented in Table 6. Only one channel of analog data is indicated. At the increased tape speed the high frequency components do not exceed the band capabilities of either the tape or the radio. Five experiments are shown with digital output. Their combined total is 305 bits per frame. With slow tape speed the bit rate acceptable is 1600 per second. The data therefore may be introduced sequentially to the tape recorder in any convenient format in 0.2 second and the registers may be cleared for the data of the next frame. Nine experiments are shown with data on film in addition to the UV spectral data. They represent 18 pounds which must be returned to Earth. The total film weight budget is:

High resolution photography	110.8 lb
Five multispectral films	69.2
UV spectra	8.0
Nine experiments on 8 mm film	<u>18.0</u>
Total returned to Earth	196.0

RESULTS AND CONCLUSIONS

The results of a successful lunar orbiter mission will appear as a unified set of geophysical measurements of the lunar surface properties. A number of man months will be required to analyze the data and to reveal the many lunar surface facts which are hidden. Additional work is also required for the application of these facts in the space program or in formulating additional lunar problems.

Several experiments have been deferred which would make Flight 511 more nearly complete. The gravity gradient experiment has stimulated interest and thought and would produce desirable measurements^{14, 22}. The feasibility of suitable apparatus has been questioned and no reports of actual tests have been found¹⁸.

The lunar probes are also deferred for further development. These secondary space missiles have not been reported in other than conceptual design¹⁸. Operation of these probes in their conceptual form requires changing course of the lunar orbiter, and hence places the other mission objectives in jeopardy.

A number of laser methods have been deferred for further development. The use of this light beam as a radar and as a communications link very probably can be done. The lack of report material and the recent difficulties in laser contact between Gemini and MSFC have reduced the priority for investigations in this field.

The magnetometer experiments are also bypassed for this mission in spite of several reports in the Journal of Geophysical Research concerning rocket borne tests of the Earth's field. Additional study may delineate feasible experiments and desirable objectives for a lunar orbiter magnetometer.

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DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) Research Laboratories Brown Engineering Company, Inc. Huntsville, Alabama		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP N/A
3. REPORT TITLE "A Mission For Surveying and Mapping the Lunar Surface"		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Note, April 1966		
5. AUTHOR(S) (Last name, first name, initial) Heaps, Stanley N.		
6. REPORT DATE April 1966	7a. TOTAL NO. OF PAGES 84	7b. NO. OF REFS 22
8a. CONTRACT OR GRANT NO. NAS8-20166	9a. ORIGINATOR'S REPORT NUMBER(S) TN R-192	
b. PROJECT NO. N/A		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.	None	
10. AVAILABILITY/LIMITATION NOTICES None		
11. SUPPLEMENTARY NOTES None	12. SPONSORING MILITARY ACTIVITY Research Projects Laboratory George C. Marshall Space Flight Center NASA	
13. ABSTRACT A three-man lunar mission has been planned in which eleven remote sensing instruments are operated for eight days in a polar orbit. From the elevation of 81.5 km (44 n mi), the high resolution stereoscopic photographs and celestial navigation sightings provide accurate location data for the Earth-science observations. The mission is one of a series proposed under the Apollo Applications Program		14. KEY WORDS lunar orbital experiments remote sensing lunar geophysics satellite instrumentation